The Use of WinSLAMM at Naval Bases to Predict Stormwater Pollutant Sources and to Identify Treatment Options

San Diego, CA, Norfolk, VA, and Puget Sound, WA Naval Bases

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Introduction

This report is a continuation of the similar document prepared last year describing the site investigations, site surveys, and stormwater modeling activities at naval facilities. These reports were prepared to demonstrate how WinSLAMM, the Source Loading and Management Model, can be used to facilitate stormwater management at naval facilities to identify sources of flows and pollutants of concern, and to evaluate potential stormwater control practices that may be applicable to these unique areas.

This report includes information for several outfall drainage areas on the “dry side” of Naval Base San Diego comprising residential, commercial, and institutional land uses, along with the industrial Sierra Pier at Subase San Diego. Two sites at Norfolk, VA, naval facilities were also investigated, Little Creek and St. Juliennes Creek Annex, which included an industrial facility and a scrapyard and storage area. Three areas were also investigated in the Puget Sound area of Washington, at the Bangor, Bremerton, and Everett naval bases, comprising industrial areas and piers. These areas were selected to supplement the other San Diego and Puget Sound facilities reported in the initial modeling report.

Data are presented for these sites describing site soil, weather, and land development conditions. Available water quality data are also summarized and used to calibrate WinSLAMM for each site. Additional analyses were also conducted investigating first flush vs. composite water quality and seasonal first flush conditions. After WinSLAMM calibration using this available data, the model was used to calculate the sources of the flows, TSS, copper, and zinc at these naval bases. The variety of conditions on these bases, along with the evaluation of the other San Diego and Puget Sound naval bases from the prior modeling report, represent a wide range of conditions at navy facilities and show how WinSLAMM can be used to assist navy facility stormwater managers.

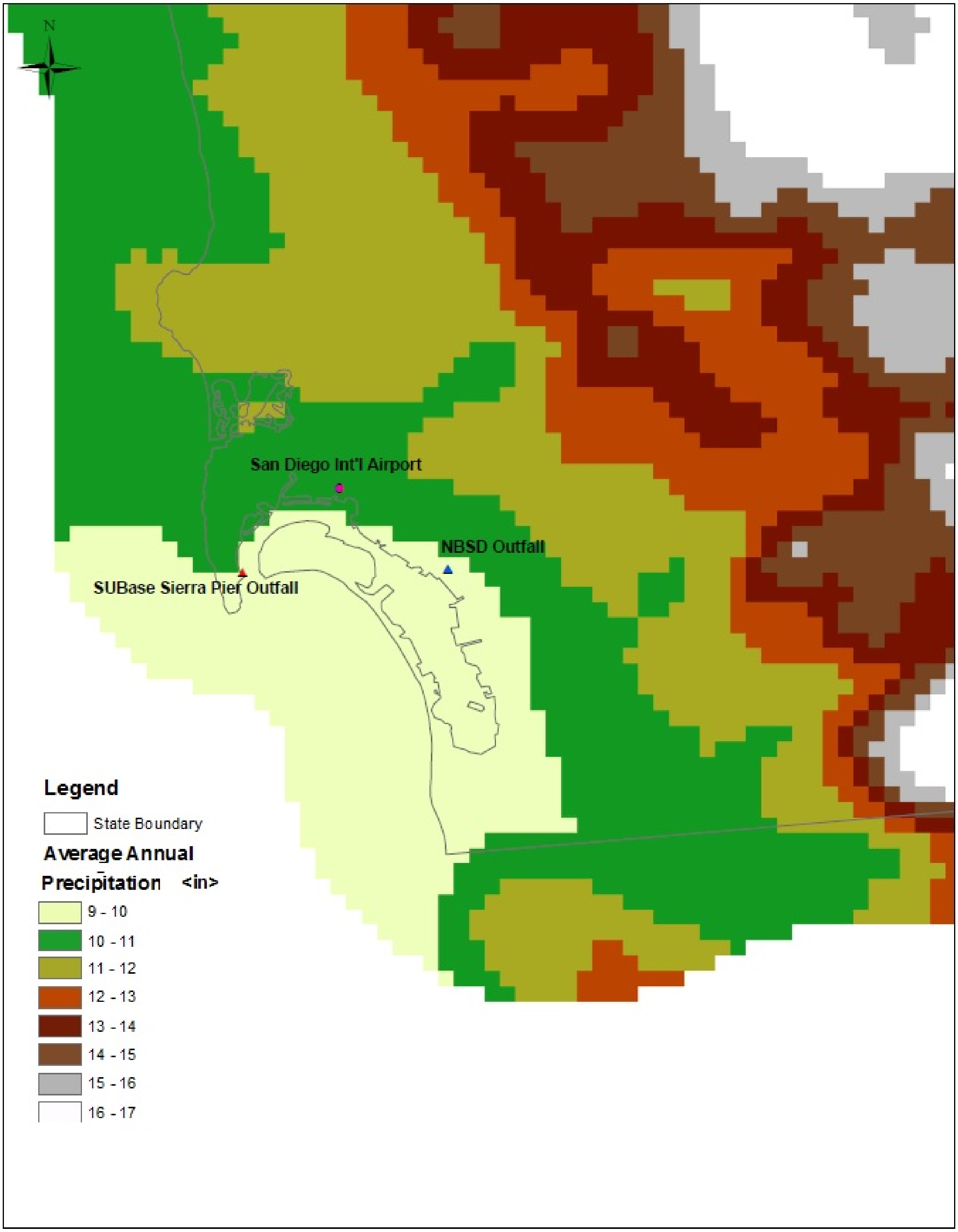
San Diego Naval Facilities

Soil Conditions at San Diego Naval Bases

According to information from the USDA web soil survey, the bases examined this year in the San Diego area have soils classified as the urban land soil type. Typically urban land includes buildings and areas of pavement. The soils are covered by asphalt roadways or parking lots, concrete structures, and other impervious surfaces. The soils have been so altered by the urban works that specific identification is not feasible. The soils can be severely compacted with very low infiltration rates in developed areas due to building construction or activities.

Rain Data for San Diego Naval Bases

The bases in the San Diego study area are located along the shore of San Diego Bay, California. The following figure shows the locations for the naval bases and the nearby weather station, along with the annual average annual rain depths for the region. The San Diego rain variations are quite small and are represented by the rain monitoring located at the San Diego International Airport.



Map of San Diego Naval Bases being studied and nearby weather station.

NOAA Precipitation Data

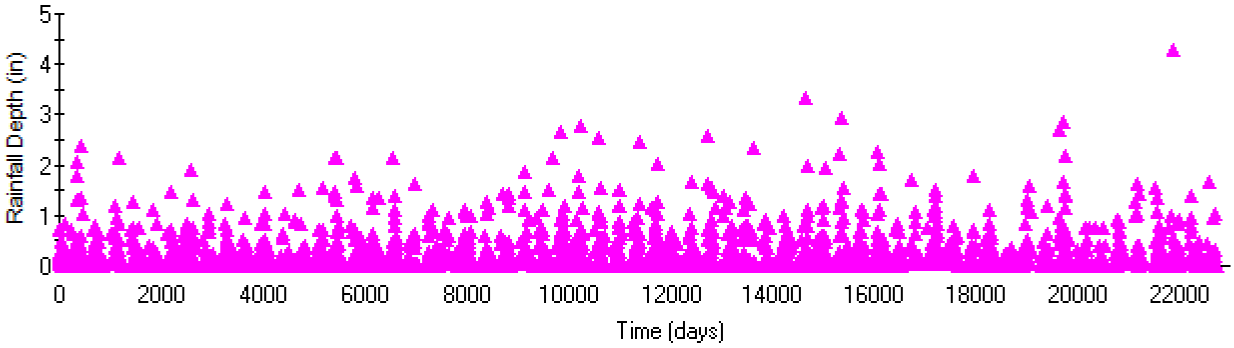
Hourly precipitation data is archived by the National Climate Data Center (NCDC) of the National Oceanic and Atmospheric Administration (NOAA). The San Diego International Airport weather station is in close proximity to the study areas and shown on the preceding map. The following table shows the approximate range of historical data available for the airport weather station, along with the completeness of the data record.

Stations with Hourly Precipitation Data included for Southwest Naval Stations

Station	COOPID	Latitude	Longitude	Data Range	% Completeness
San Diego Lindbergh Field	047740	32.733	-117.183	1948-2012	98

Rainfall Patterns for Southwest Naval Bases

The following time series plot shows the rain depths for each rain that occurred during the period of 1951 through 2013, including the stormwater monitoring period. Most of the San Diego rains are less than 1 inch, with occasional rains greater than 2 inches.



San Diego Lindbergh Field, CA, rainfall from January 1951 to April 2013

The regional naval facilities and the closest available NOAA rainfall data are summarized below:

Sub Base Sierra Pier: 9 to 10 in/yr (San Diego Lindbergh Field, 10 in/yr between 1981 and 2010)
NBSD: 9 to 10 in/yr (San Diego Lindbergh Field, 10 in/yr between 1981 and 2010)

Therefore, the WinSLAMM calibration efforts will focus on the San Diego Lindbergh Field NOAA data for Sub Base Sierra Pier and NBSD Naval facilities due to its close proximity and rain conditions.

Submarine Base San Diego (SUBASE) – Sierra Pier Outfalls 26, 26A, 27, 28, 28A

Submarine Base Sand Diego (SUBASE) is located along the eastern shore of San Diego Bay. At this base, 5 outfalls were examined on the Sierra Pier. A complete data survey is available for this area describing the surface coverage, and area of each surface type. The watershed area for this outfall is approximately 6.4 acres. The site is mainly comprised of several small buildings, and expansive impervious areas (parking lots, storage and lay down areas). The site is completely paved without any pervious areas.

Drainage Overview for Sierra Pier Outfalls

Aerial Outline and Land use characterization for NBSD Outfall 51

 ARCO utility cable racks	 Treated wood
 Treated wood and scaffolding	 Bldg. 633 southwest corner roof drains
 Bldg. 633 roof	 Laydown area sampled on Dec 13, 2012

Photos taken during site surveys

Land Use Characterization for Sierra Pier Outfalls 26, 26A, 27, 28, 28A Combined

LANDUSE	**Area (ac)**
Roofs	
1 Roofs Flat - directly connected to drains	0
2 Roofs Flat - drains to asphalt/concrete	0.55
3 Roofs Flat - drains to soils	0
4 Roofs Flat - drains to vegetation	0
5 Roofs Flat - drains to other surface (artificial turf, rock, gravel, etc.)	0
6 Roofs Pitched - directly connected	0
7 Roofs Pitched - drains to asphalt/concrete	0.29
8 Roofs Pitched - drains to soils	0
9 Roofs Pitched - drains to vegetation	0
10 Roofs Pitched - drains to other surface (artificial turf, rock, gravel, etc.)	0
Parking/Streets/Sidewalks/Driveways	
13 Paved asphalt parking/storage - smooth/intermediate texture - directly connected to drains	0
14 Paved asphalt parking/storage - rough/very course texture - directly connected to drains	0
15 Paved asphalt parking/storage - drains to pervious	0
16 Paved concrete parking/storage - smooth - directly connected	0.22
17 Paved concrete parking/storage - intermediate - directly connected	0
18 Paved concrete parking/storage - drains to pervious	0
19 Unpaved parking/storage - directly connected to drains	0
20 Unpaved parking/storage - drains to pervious	0
25 Driveways/loading dock -asphalt- directly connected	0.23
26 Driveways/loading dock -concrete- directly connected	0.40
27 Driveways/loading dock - drains to pervious	0
31 Sidewalks - directly connected to drains	0
32 Sidewalks - drains to pervious	0
37 Streets- directly connected to drains	0
38 Streets-drains to pervious	0
Pervious Areas	
45 Landscaping areas - soils	0
46 Landscaping areas - vegetation	0
51 Landscaping areas around structures- soils	0
52 Landscaping areas around structures - vegetation	0
53 Landscaping areas around structures- other/infiltration area	0
57 Undeveloped areas - soils	0
58 Undeveloped areas - vegetation	0
71 Other pervious infiltration areas	0

Land Use Characterization for Sierra Pier Outfalls 26, 26A, 27, 28, 28A Combined (continued)

Special Areas	
84 OIA1 - Airfield apron/runway paved areas - directly connected	0
OIA1 - Airfield apron/runway paved areas- drains to soil	0
OIA1 - Airfield apron/runway paved areas - drains to vegetation	0
85 OIA2 - Airfield other paved areas- directly connected	0
OIA2 - Airfield other paved areas- drains to soil	0
OIA2 - Airfield other paved areas- drains to vegetation	0
86 OIA3 - Light laydown concrete areas- directly connected to drains	0.74
OIA3 - Light laydown concrete areas - drains to soil	0
OIA3 - Light laydown concrete areas - drains to vegetation	0
87 OIA4 - Moderate laydown concrete areas - directly connected	1.08
OIA4 - Moderate laydown concrete areas - drains to soil	0
OIA4 - Moderate laydown concrete areas - drains to vegetation	0
88 OIA5 - Heavy laydown concrete areas- directly connected	0
OIA5 - Heavy laydown concrete areas - drains to soil	0
OIA5 - Heavy laydown concrete areas- drains to vegetation	0
89 OIA6 - Light laydown asphalt areas - directly connected	0
OIA6 - Light laydown asphalt areas- drains to soil	0
OIA6 - Light laydown asphalt areas- drains to vegetation	0
90 OIA7 - Moderate laydown asphalt areas- directly connected	0
OIA7 - Moderate laydown asphalt areas- drains to soil	0
OIA7 - Moderate laydown asphalt areas- drains to vegetation	0
91 OIA8 - Heavy laydown asphalt areas - directly connected	0
OIA8 - Heavy laydown asphalt areas - drains to soil	0
OIA8 - Heavy laydown asphalt areas - drains to vegetation	0
92 OIA9 - Galvanized metal roofs- directly connected	0
OIA9 - Galvanized metal roofs - drains to soil	0
OIA9 - Galvanized metal roofs- drains to vegetation	0
93 OIA10 - Other galvanized materials- directly connected to drains	0.91
OIA10 - Other galvanized materials - drains to soil	0
OIA10 - Other galvanized materials - drains to vegetation	0

Land Use Characterization for Sierra Pier Outfalls 26, 26A, 27, 28, 28A Combined (continued)

99 ONPIA11 - Light laydown unpaved - drains to soil	0
99 ONPA11 - Light laydown unpaved - drains to vegetation	0
100 ONPA12 - Moderate laydown unpaved - drains to soil	0
101 ONPA12 - Moderate laydown unpaved - drains to vegetation	0
102 ONPA13 - Heavy laydown unpaved - drains to soil	0
103 ONPA13 - Heavy laydown unpaved - drains to vegetation	0
Total Area (acres)	4.42

Water Quality Monitoring Data for Sierra Pier Outfalls 26, 26A, 27, 28, 28A Combined

Date	Outfall	TSS (mg/L)	Total Copper (µg/L)	Total Zinc (µg/L)	Dissolved Copper (µg/L)	Associated Rain Day/ Event	Event Rain Depth (inches)
4-Feb-94	28	425	2750	5220		2/3/94 17:00 to 2/4/94 14:00	0.69
10-Nov-94	26	8.0				11/10/94 8:00 to 11/10/94 14:00	0.21
10-Nov-94	27	130				11/10/94 8:00 to 11/10/94 14:00	0.21
10-Nov-94	28	170				11/10/94 8:00 to 11/10/94 14:00	0.21
21-Jan-96	26	5260	1030	2540		1/21/96 18:00 to 1/21/96 20:00	0.22
13-Mar-96	26	149	140	413		3/12/96 16:00 to 3/13/96 10:00	0.67
13-Mar-96	27	11				3/12/96 16:00 to 3/13/96 10:00	0.67
13-Mar-96	28	88				3/12/96 16:00 to 3/13/96 10:00	0.67
21-Nov-96	26	10	77	223		11/21/96 16:00 to 11/22/96 6:00	1.69
21-Nov-96	27	40				11/21/96 16:00 to 11/22/96 6:00	1.69
21-Nov-96	28	79				11/21/96 16:00 to 11/22/96 6:00	1.69
10-Feb-97	26	6	101	187		2/10/97 18:00 to 2/10/97 21:00	0.2
10-Feb-97	27	8				2/10/97 18:00 to 2/10/97 21:00	0.2
10-Feb-97	28	23				2/10/97 18:00 to 2/10/97 21:00	0.2
13-Nov-97	26	74	1740	1950		11/13/97 6:00 to 11/13/97 15:00	0.44
13-Nov-97	27	11.0				11/13/97 6:00 to 11/13/97 15:00	0.44
13-Nov-97	28	112				11/13/97 6:00 to 11/13/97 15:00	0.44
9-Jan-98	26	17.0	325	432		1/9/98 9:00 to 1/10/98 9:00	1.1
9-Jan-98	27	20				1/9/98 9:00 to 1/10/98 9:00	1.1
9-Jan-98	28	22				1/9/98 9:00 to 1/10/98 9:00	1.1
25-Jan-99	26	32	794	1700		1/25/99 3:00 to 1/26/99 4:00	0.79
25-Jan-99	27	ND				1/25/99 3:00 to 1/26/99 4:00	0.79
25-Jan-99	28	27				1/25/99 3:00 to 1/26/99 4:00	0.79
11-Mar-99	27	130				3/11/99 11:00 to 3/11/99 13:00	0.17
15-Mar-99	26	71	1000	3090		3/15/99 8:00 to 3/15/99 12:00	0.16

Water Quality Monitoring Data for Sierra Pier Outfalls 26, 26A, 27, 28, 28A Combined (continued)

15-Mar-99	28	87				3/15/99 8:00 to 3/15/99 12:00	0.16
12-Feb-00	26	256	517	679		2/12/00 3:00 to 2/12/00 10:00	0.39
12-Feb-00	28	32				2/12/00 3:00 to 2/12/00 10:00	0.39
20-Feb-00	27	175				2/20/00 4:00 to 2/20/00 10:00	0.33
17-Apr-00	26	9.0	87.5	140		4/17/00 15:00 to 4/17/00 19:00	0.41
17-Apr-00	27	8.0				4/17/00 15:00 to 4/17/00 19:00	0.41
17-Apr-00	28	152				4/17/00 15:00 to 4/17/00 19:00	0.41
27-Oct-00	26	65	1350	628		10/27/00 6:00 to 10/27/00 10:00	0.31
27-Oct-00	27	184	1150	3560		10/27/00 6:00 to 10/27/00 10:00	0.31
27-Oct-00	28	130	4080	2850		10/27/00 6:00 to 10/27/00 10:00	0.31
24-Jan-01	26	176	1940	2120		1/24/01 11:00 to 1/24/01 16:00	0.06
24-Jan-01	27	300	2860	9350		1/24/01 11:00 to 1/24/01 16:00	0.06
24-Jan-01	28	92	3610	3400		1/24/01 11:00 to 1/24/01 16:00	0.06
24-Nov-01	26	6.0	125	441	112	11/24/01 17:00 to 11/24/01 19:00	0.22
24-Nov-01	27	36.0	53.7	138	46.6	11/24/01 17:00 to 11/24/01 19:00	0.22
24-Nov-01	28	44.0	210	205	183	11/24/01 17:00 to 11/24/01 19:00	0.22
24-Apr-02	26	100	1820	1790	1580	4/24/02 8:00 to 4/24/02 12:00	0.22
24-Apr-02	27	78.0	295	693	250	4/24/02 8:00 to 4/24/02 12:00	0.22
24-Apr-02	28	78.0	650	685	561	4/24/02 8:00 to 4/24/02 12:00	0.22
15-Mar-03	26	43	230	700		3/15/03 10:00 to 3/16/03 3:00	1.16
15-Mar-03	27	18	46	1900		3/15/03 10:00 to 3/16/03 3:00	1.16
15-Mar-03	28	81				3/15/03 10:00 to 3/16/03 3:00	1.16
3-May-03	26	19	540	1300		5/3/03 4:00 to 5/3/03 13:00	0.3
3-May-03	27	36	140	340		5/3/03 4:00 to 5/3/03 13:00	0.3
3-May-03	28	190	560	420		5/3/03 4:00 to 5/3/03 13:00	0.3
1-Apr-04	26	130	960	2000		4/1/04 17:00 to 4/1/04 23:00	0.3
1-Apr-04	27	370	200	820		4/1/04 17:00 to 4/1/04 23:00	0.3
1-Apr-04	28	280	2600	1300		4/1/04 17:00 to 4/1/04 23:00	0.3

Water Quality Monitoring Data for Sierra Pier Outfalls 26, 26A, 27, 28, 28A Combined (continued)

17-Apr-04	26	31	420	750		4/17/04 10:00 to 4/17/04 13:00	0.3
17-Apr-04	27	26	290	1100		4/17/04 10:00 to 4/17/04 13:00	0.3
17-Apr-04	28	110	2100	1100		4/17/04 10:00 to 4/17/04 13:00	0.3
28-Jan-05	26	84	730	1000		1/28/05 15:00 to 1/28/05 19:00	0.41
28-Jan-05	27	33	37	80		1/28/05 15:00 to 1/28/05 19:00	0.41
28-Jan-05	28	310	420	310		1/28/05 15:00 to 1/28/05 19:00	0.41
11-Feb-05	26	39	130	230		2/10/05 13:00 to 2/12/05 0:00	1.39
11-Feb-05	27	120	400	620		2/10/05 13:00 to 2/12/05 0:00	1.39
11-Feb-05	28	330	120	200		2/10/05 13:00 to 2/12/05 0:00	1.39
17-Oct-05	26	60	570	1100		10/17/05 11:00 to 10/17/05 14:00	0.33
17-Oct-05	27	240	450	1500		10/17/05 11:00 to 10/17/05 14:00	0.33
17-Oct-05	28	62	950	1300		10/17/05 11:00 to 10/17/05 14:00	0.33
10-Mar-06	26	210	720	1500		3/10/06 5:00 to 3/10/06 7:00	0.08
10-Mar-06	27	490	640	2400		3/10/06 5:00 to 3/10/06 7:00	0.08
10-Mar-06	28	890	1800	1600		3/10/06 5:00 to 3/10/06 7:00	0.08
27-Dec-06	26	59	130	180		12/27/06 6:00 to 12/27/06 8:00	0.15
27-Dec-06	27	4.8	64	1300		12/27/06 6:00 to 12/27/06 8:00	0.15
27-Dec-06	28	9.8	130	170		12/27/06 6:00 to 12/27/06 8:00	0.15
20-Apr-07	26	180	690	2500		4/20/07 12:00 to 4/21/07 0:00	0.38
20-Apr-07	27	12	83	2100		4/20/07 12:00 to 4/21/07 0:00	0.38
20-Apr-07	28	160	1500	2200		4/20/07 12:00 to 4/21/07 0:00	0.38
14-Feb-08	26	130	920	2200		2/14/08 9:00 to 2/14/08 17:00	0.21
14-Feb-08	27	58	73	2000		2/14/08 9:00 to 2/14/08 17:00	0.21
14-Feb-08	28	140	2000	4100		2/14/08 9:00 to 2/14/08 17:00	0.21
4-Nov-08	28	38	2800	8700		11/4/08 8:00 to 11/4/08 11:00	0.14
15-Dec-08	26	96	820	2700		12/15/08 8:00 to 12/16/08 1:00	1.02
15-Dec-08	27	38	380	880		12/15/08 8:00 to 12/16/08 1:00	1.02
15-Dec-08	28	140	1400	2800		12/15/08 8:00 to 12/16/08 1:00	1.02

Water Quality Monitoring Data for Sierra Pier Outfalls 26, 26A, 27, 28, 28A Combined (continued)

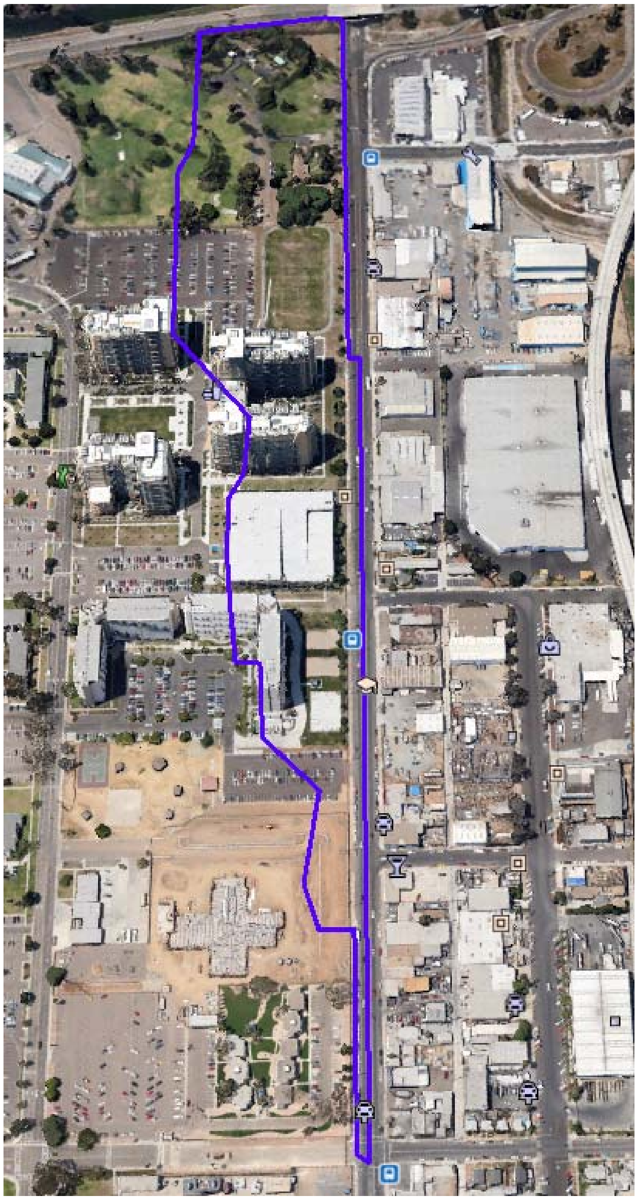
7-Dec-09	26	93	600	2200		12/7/09 3:00 to 12/7/09 17:00	1.56
7-Dec-09	27	100	150	630		12/7/09 3:00 to 12/7/09 17:00	1.56
7-Dec-09	28	130	330	800		12/7/09 3:00 to 12/7/09 17:00	1.56
18-Jan-10	26	37	110	340		1/18/10 14:00 to 1/18/10 17:00	1.06
18-Jan-10	27	30	82	290		1/18/10 14:00 to 1/18/10 17:00	1.06
18-Jan-10	28	90	270	660		1/18/10 14:00 to 1/18/10 17:00	1.06
19-Oct-10	26	14	320	600		10/19/10 10:00 to 10/20/10 2:00	1.01
19-Oct-10	27	13	320	710		10/19/10 10:00 to 10/20/10 2:00	1.01
19-Oct-10	28	9.0	390	380		10/19/10 10:00 to 10/20/10 2:00	1.01
18-May-11	26	4.0	48	94		5/18/11 2:00 to 5/18/11 6:00	0.19
18-May-11	27	7.5	58	360		5/18/11 2:00 to 5/18/11 6:00	0.19
18-May-11	28	7.5	99	340		5/18/11 2:00 to 5/18/11 6:00	0.19
4-Nov-11	26	6.5	510	1300		11/4/11 8:00 to 11/5/11 1:00	0.66
4-Nov-11	27	ND	270	310		11/4/11 8:00 to 11/5/11 1:00	0.66
4-Nov-11	28	7.5	780	2100		11/4/11 8:00 to 11/5/11 1:00	0.66
12-Dec-11	26	34	530	4100		12/12/11 7:00 to 12/13/11 13:00	0.8
12-Dec-11	27	12	110	280		12/12/11 7:00 to 12/13/11 13:00	0.8
12-Dec-11	28	31	370	790		12/12/11 7:00 to 12/13/11 13:00	0.8
7-Feb-12	26-A		190	560		2/7/12 14:00 to 2/7/12 18:00	0.29
7-Feb-12	28-A		290	1100		2/7/12 14:00 to 2/7/12 18:00	0.29

Naval Base San Diego (NBSD) – Outfalls 51, 70, 72, and 73

Naval Base San Diego (NBSD) is located on the mainland of San Diego along the eastern shore of the bay. Four outfalls were examined at his base: Outfalls 51, 70, 72, and 73. All the outfalls examined have complete data surveys available describing the coverage, including the areas of each surface type.

Outfall 51

Outfall 51 (located adjacent to outfall 70) is comprised of a mix of residential and commercial land uses, with several buildings, parking lots, storage and landscaped areas. The watershed area for this outfall is approximately 19 acres. This site has landscaping areas inside the watershed boundary that make up 56% of the total drainage area. An aerial photograph of the watershed is shown in the following figure.



Aerial view and Outline of NBSD Outfall 51

Drainage overview and Land use characterization for NBSD Outfall 51

NBSD OF51 Site Development Characteristics

	NBSD OF-51		
	Residential	**Other Urban**	**Total**
Roofs	**(ac)**	**(ac)**	**(ac)**
1 Roofs Flat - directly connected to drains	0.81	0	0.81
2 Roofs Flat - drains to asphalt/concrete	0	0	0
3 Roofs Flat - drains to soils	0	0	0
4 Roofs Flat - drains to vegetation	0	0	0
5 Roofs Flat - drains to other surface (artificial turf, rock, gravel, etc.)	0	0	0
6 Roofs Pitched - directly connected	0	0	0
7 Roofs Pitched - drains to asphalt/concrete	0	0	0
8 Roofs Pitched - drains to soils	0	0	0
9 Roofs Pitched - drains to vegetation	0.15	0	0.15
10 Roofs Pitched - drains to other surface (artificial turf, rock, gravel, etc.)	0	0	0
Parking/Streets/Sidewalks/Driveways			
13 Paved asphalt parking/storage - smooth/intermediate texture - directly connected to drains	3.42	0	3.42
14 Paved asphalt parking/storage - rough/very course texture - directly connected to drains	0	0	0
15 Paved asphalt parking/storage - drains to pervious	0.77	0	0.77
16 Paved concrete parking/storage - smooth - directly connected	0	0	0
17 Paved concrete parking/storage - intermediate - directly connected	1.31	0	1.31
18 Paved concrete parking/storage - drains to pervious	0.02	0	0.02
19 Unpaved parking/storage - directly connected to drains	0	0	0
20 Unpaved parking/storage - drains to pervious	0	0	0
25 Driveways/loading dock -asphalt- directly connected	0	0	0
26 Driveways/loading dock -concrete- directly connected	0	0	0
27 Driveways/loading dock - drains to pervious	0.35	0	0.35
31 Sidewalks - directly connected to drains	0.46	0	0.46
32 Sidewalks - drains to pervious	0.66	0	0.66
37 Streets- directly connected to drains	0	0	0
38 Streets-drains to pervious	0	0	0

NBSD OF51 Site Development Characteristics (continued)

Pervious Areas			
45 Landscaping areas - soils	0	0	0
46 Landscaping areas - vegetation	4.35	5.95	10.31
51 Landscaping areas around structures- soils	0	0	0
52 Landscaping areas around structures - vegetation	0.16	0	0.16
53 Landscaping areas around structures- other/infiltration area	0	0	0
57 Undeveloped areas - soils	0	0.23 (construction)	0.23
58 Undeveloped areas - vegetation	0	0	0
71 Other pervious infiltration areas	0	0	0
Special Areas			
84 OIA1 - Airfield apron/runway paved areas - directly connected	0	0	0
OIA1 - Airfield apron/runway paved areas- drains to soil	0	0	0
OIA1 - Airfield apron/runway paved areas - drains to vegetation	0	0	0
85 OIA2 - Airfield other paved areas- directly connected	0	0	0
OIA2 - Airfield other paved areas- drains to soil	0	0	0
OIA2 - Airfield other paved areas- drains to vegetation	0	0	0
86 OIA3 - Light laydown concrete areas- directly connected to drains	0	0	0
OIA3 - Light laydown concrete areas - drains to soil	0	0	0
OIA3 - Light laydown concrete areas - drains to vegetation	0	0	0
87 OIA4 - Moderate laydown concrete areas - directly connected	0.06	0	0.06
OIA4 - Moderate laydown concrete areas - drains to soil	0	0	0
OIA4 - Moderate laydown concrete areas - drains to vegetation	0	0	0
88 OIA5 - Heavy laydown concrete areas- directly connected	0	0	0
OIA5 - Heavy laydown concrete areas - drains to soil	0	0	0
OIA5 - Heavy laydown concrete areas- drains to vegetation	0	0	0

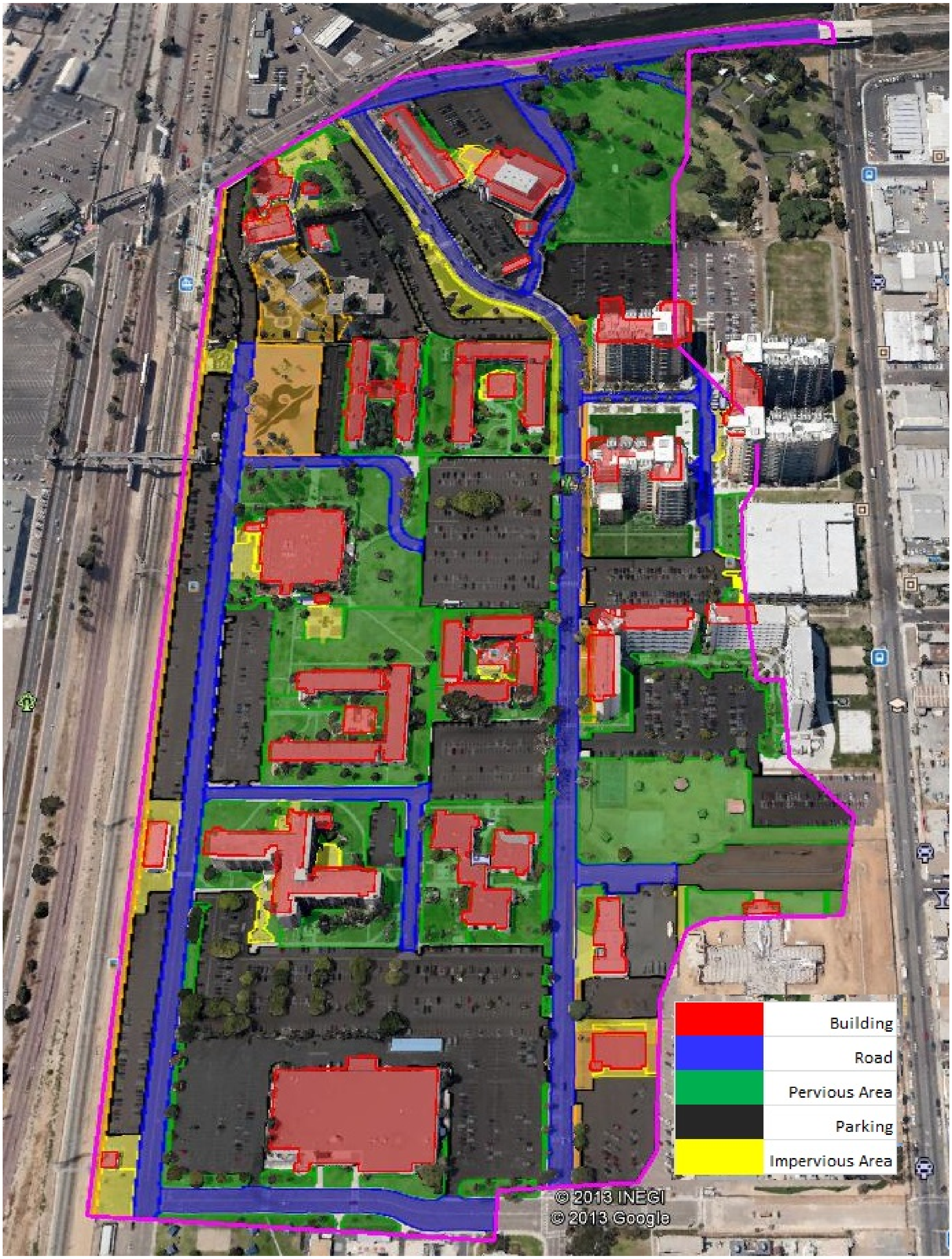
NBSD OF51 Site Development Characteristics (continued)

89 OIA6 - Light laydown asphalt areas - directly connected	0	0	0
OIA6 - Light laydown asphalt areas- drains to soil	0	0	0
OIA6 - Light laydown asphalt areas- drains to vegetation	0	0	0
90 OIA7 - Moderate laydown asphalt areas- directly connected	0	0	0
OIA7 - Moderate laydown asphalt areas- drains to soil	0	0	0
OIA7 - Moderate laydown asphalt areas- drains to vegetation	0	0	0
91 OIA8 - Heavy laydown asphalt areas - directly connected	0	0	0
OIA8 - Heavy laydown asphalt areas - drains to soil	0	0	0
OIA8 - Heavy laydown asphalt areas - drains to vegetation	0	0	0
92 OIA9 - Galvanized metal roofs- directly connected	0	0	0
OIA9 - Galvanized metal roofs - drains to soil	0	0	0
OIA9 - Galvanized metal roofs- drains to vegetation	0	0	0
93 OIA10 - Other galvanized materials- directly connected to drains	0	0	0
OIA10 - Other galvanized materials - drains to soil	0.48	0	0.48
OIA10 - Other galvanized materials - drains to vegetation	0	0	0
99 ONPIA11 - Light laydown unpaved - drains to soil	0	0	0
99 ONPA11 - Light laydown unpaved - drains to vegetation	0	0	0
100 ONPA12 - Moderate laydown unpaved - drains to soil	0	0	0
101 ONPA12 - Moderate laydown unpaved - drains to vegetation	0	0	0
102 ONPA13 - Heavy laydown unpaved - drains to soil	0	0	0
103 ONPA13 - Heavy laydown unpaved - drains to vegetation	0	0	0
Total Area (acres)	13.02	6.18	19.19

Outfall 70

Outfall 70 (located adjacent to outfall 51) is comprised of a mixture of residential and commercial land uses, with buildings, landscaping, parking lots and light to moderate laydown concrete covered areas. This is the largest of the San Diego study areas with a watershed area of approximately 78 acres. This site has pervious area accounting up to 34 % of the total drainage area. An aerial photograph of the watershed is shown in the following figure.

Aerial view and Outline of NBSD Outfall 70



Drainage overview and Land use characterization for NBSD Outfall 70

Photos taken during site surveys

NBSD OF70 Development Characteristics

	NBSD OF-70				
	Residential	**Commercial**	**Institutional**	**Other Urban**	**Total**
Roofs	**(ac)**	**(ac)**	**(ac)**	**(ac)**	**(ac)**
1 Roofs Flat - directly connected to drains	0.45	2.40	0	0	2.85
2 Roofs Flat - drains to asphalt/concrete	0.06	1.41	0	0	1.47
3 Roofs Flat - drains to soils	0.17	0	0	0	0.17
4 Roofs Flat - drains to vegetation	0.95	0.18	0	0	1.13
5 Roofs Flat - drains to other surface (artificial turf, rock, gravel, etc.)	0	0	0	0	0
6 Roofs Pitched - directly connected	0	0	0	0	0
7 Roofs Pitched - drains to asphalt/concrete	0.23	1.20	0.10	0	1.53
8 Roofs Pitched - drains to soils	0	0	0.14	0	0.14
9 Roofs Pitched - drains to vegetation	1.81	1.22	0	0	3.02
10 Roofs Pitched - drains to other surface (artificial turf, rock, gravel, etc.)	0	0	0	0	0
Parking/Streets/Sidewalks/Driveways					
13 Paved asphalt parking/storage - smooth/intermediate texture - directly connected to drains	2.54	0	0	0	2.54
14 Paved asphalt parking/storage - rough/very course texture - directly connected to drains	13.08	4.15	0	0	17.23
15 Paved asphalt parking/storage - drains to pervious	4.54	2.27	0	0	6.82
16 Paved concrete parking/storage - smooth - directly connected	0.50	0	0	0	0.50
17 Paved concrete parking/storage - intermediate - directly connected	0	0	0	0	0
18 Paved concrete parking/storage - drains to pervious	0.37	0	0	0	0.37
19 Unpaved parking/storage - directly connected to drains	0	0	0	0	0
20 Unpaved parking/storage - drains to pervious	0	0	0	0.78 (construction)	0.78
25 Driveways/loading dock -asphalt-directly connected	0.08	0	0	0	0.08
26 Driveways/loading dock -concrete-directly connected	0.11	0	0	0	0.11
27 Driveways/loading dock - drains to pervious	0.59	0.52	0	0	1.11

NBSD OF70 Development Characteristics (continued)

31 Sidewalks - directly connected to drains	0.73	0.23	0	0	0.96
32 Sidewalks - drains to pervious	0	0	0	0	0
37 Streets- directly connected to drains	5.79	2.26	0	2.65	10.70
38 Streets-drains to pervious	0	0	0	0	0
Pervious Areas					
45 Landscaping areas - soils	0	0	0	0	0
46 Landscaping areas - vegetation	12.64	2.16	0	6.34	21.14
51 Landscaping areas around structures- soils	0	0	0	0	0
52 Landscaping areas around structures - vegetation	0.33	0.15	0	0	0.49
53 Landscaping areas around structures- other/infiltration area	0.30	0	0	0	0.30
57 Undeveloped areas - soils	0	0	0	0.23 (construction)	0.23
58 Undeveloped areas - vegetation	0	0	0	0	0
71 Other pervious infiltration areas	0.35	0.09	0	3.93	4.37
Special Areas					
84 OIA1 - Airfield apron/runway paved areas - directly connected	0	0	0	0	0
OIA1 - Airfield apron/runway paved areas- drains to soil	0	0	0	0	0
OIA1 - Airfield apron/runway paved areas - drains to vegetation	0	0	0	0	0
85 OIA2 - Airfield other paved areas- directly connected	0	0	0	0	0
OIA2 - Airfield other paved areas- drains to soil	0	0	0	0	0
OIA2 - Airfield other paved areas- drains to vegetation	0	0	0	0	0
86 OIA3 - Light laydown concrete areas- directly connected to drains	0.03	0	0	0	0.03
OIA3 - Light laydown concrete areas - drains to soil	0	0	0	0	0
OIA3 - Light laydown concrete areas - drains to vegetation	0	0	0	0	0
87 OIA4 - Moderate laydown concrete areas - directly connected	0	0	0	0	0

NBSD OF70 Development Characteristics (continued)

OIA4 - Moderate laydown concrete areas - drains to soil	0	0	0	0	0
OIA4 - Moderate laydown concrete areas - drains to vegetation	0	0	0	0	0
88 OIA5 - Heavy laydown concrete areas- directly connected	0	0	0	0	0
OIA5 - Heavy laydown concrete areas - drains to soil	0	0	0	0	0
OIA5 - Heavy laydown concrete areas- drains to vegetation	0	0	0	0	0
89 OIA6 - Light laydown asphalt areas - directly connected	0	0.17	0	0	0.17
OIA6 - Light laydown asphalt areas- drains to soil	0	0	0	0	0
OIA6 - Light laydown asphalt areas- drains to vegetation	0	0	0	0	0
90 OIA7 - Moderate laydown asphalt areas- directly connected	0	0	0	0.04	0.04
OIA7 - Moderate laydown asphalt areas- drains to soil	0	0	0	0	0
OIA7 - Moderate laydown asphalt areas- drains to vegetation	0	0	0	0	0
91 OIA8 - Heavy laydown asphalt areas - directly connected	0	0	0	0	0
OIA8 - Heavy laydown asphalt areas - drains to soil	0	0	0	0	0
OIA8 - Heavy laydown asphalt areas - drains to vegetation	0	0	0	0	0
92 OIA9 - Galvanized metal roofs- directly connected	0	0	0	0	0
OIA9 - Galvanized metal roofs - drains to soil	0	0	0	0	0
OIA9 - Galvanized metal roofs- drains to vegetation	0	0	0	0	0
93 OIA10 - Other galvanized materials- directly connected to drains	0	0	0	0	0
OIA10 - Other galvanized materials - drains to soil	0	0	0	0	0

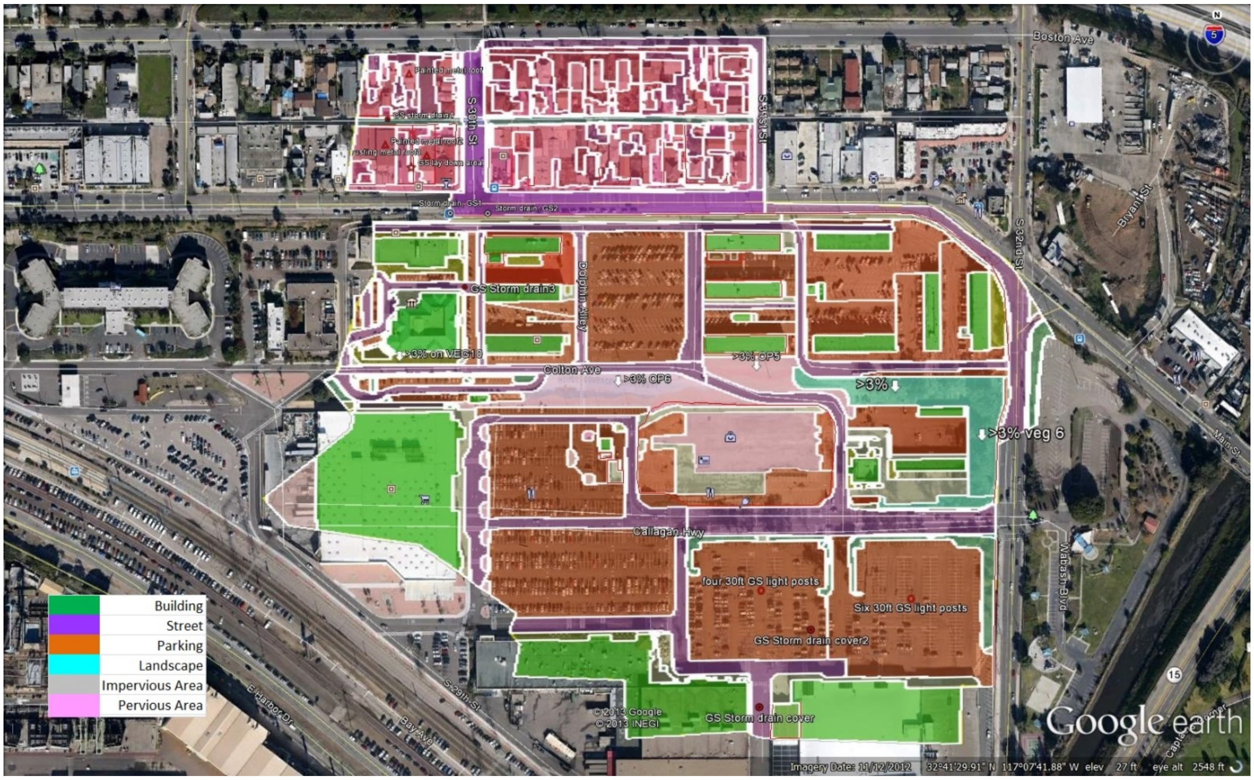
NBSD OF70 Development Characteristics (continued)

OIA10 - Other galvanized materials - drains to vegetation	0	0	0	0	0
99 ONPIA11 - Light laydown unpaved - drains to soil	0	0	0	0	0
99 ONPA11 - Light laydown unpaved - drains to vegetation	0	0	0	0	0
100 ONPA12 - Moderate laydown unpaved - drains to soil	0	0	0	0	0
101 ONPA12 - Moderate laydown unpaved - drains to vegetation	0	0	0	0	0
102 ONPA13 - Heavy laydown unpaved - drains to soil	0	0	0	0	0
103 ONPA13 - Heavy laydown unpaved - drains to vegetation	0	0	0	0	0
Total Area (acres)	45.64	18.41	0.23	13.97	78.27

Outfall 72

Outfall 72 (located adjacent to outfall 73) is comprised of a mixture of navy residential and commercial property buildings, landscaping, parking lots, and light to heavy concrete covered storage and parking areas. The watershed area for this outfall is approximately 45 acres. This site has pervious areas accounting for 14% of the total drainage area. Aerial photographs, along with different land use characteristics, are shown in the following figures.

Aerial view and Outline of NBSD Outfall 72



Drainage overview and Land use characterization for NBSD Outfall 72

NBSD OF72 Development Characteristics

	NBSD OF-72			
	Residential	Commercial	Institutional	Total
Roofs	(ac)	(ac)	(ac)	(ac)
1 Roofs Flat - directly connected to drains	0	2.69	0	2.69
2 Roofs Flat - drains to asphalt/concrete	0.71	0.57	0	1.29
3 Roofs Flat - drains to soils	0	0	0	0
4 Roofs Flat - drains to vegetation	0	0.28	0	0.28
5 Roofs Flat - drains to other surface (artificial turf, rock, gravel, etc.)	0	2.19	0	2.19
6 Roofs Pitched - directly connected	0	0	0	0
7 Roofs Pitched - drains to asphalt/concrete	2.77	1.06	0.23	4.06
8 Roofs Pitched - drains to soils	0	0	0	0
9 Roofs Pitched - drains to vegetation	0	0.03	0.23	0.26
10 Roofs Pitched - drains to other surface (artificial turf, rock, gravel, etc.)	0	0	0	0
Parking/Streets/Sidewalks/Driveways				
13 Paved asphalt parking/storage - smooth/intermediate texture - directly connected to drains	3.71	9.53	0.21	13.45
14 Paved asphalt parking/storage - rough/very course texture - directly connected to drains	1.93	1.62	0.11	3.66
15 Paved asphalt parking/storage - drains to pervious	0.06	0	0	0.06
16 Paved concrete parking/storage - smooth - directly connected	0.01	0.62	0	0.64
17 Paved concrete parking/storage - intermediate - directly connected	0.06	0.05	0	0.11
18 Paved concrete parking/storage - drains to pervious	0	0	0	0
19 Unpaved parking/storage - directly connected to drains	0	0	0	0
20 Unpaved parking/storage - drains to pervious	0	0	0	0
25 Driveways/loading dock -asphalt-directly connected	0.00	0	0	0.00
26 Driveways/loading dock -concrete-directly connected	0.30	0.21	0	0.52
27 Driveways/loading dock - drains to pervious	0	0	0	0
31 Sidewalks - directly connected to drains	0.88	0.14	0.52	1.53

NBSD OF72 Development Characteristics (continued)

32 Sidewalks - drains to pervious	0	0	0	0
37 Streets- directly connected to drains	2.89	3.29	0.26	6.44
38 Streets-drains to pervious	0	0	0	0
Pervious Areas				
45 Landscaping areas - soils	0.02	0.02	0	0.04
46 Landscaping areas - vegetation	0.68	1.86	0.02	2.56
51 Landscaping areas around structures- soils	0	0	0	0
52 Landscaping areas around structures - vegetation	0.75	0.47	0	1.21
53 Landscaping areas around structures- other/infiltration area	0	0.17	0	0.17
57 Undeveloped areas - soils	0	0	0	0
58 Undeveloped areas - vegetation	0	0	0	0
71 Other pervious infiltration areas	0.39	1.98	0	2.37
Special Areas				
84 OIA1 - Airfield apron/runway paved areas - directly connected	0	0	0	0
OIA1 - Airfield apron/runway paved areas- drains to soil	0	0	0	0
OIA1 - Airfield apron/runway paved areas - drains to vegetation	0	0	0	0
85 OIA2 - Airfield other paved areas- directly connected	0	0	0	0
OIA2 - Airfield other paved areas- drains to soil	0	0	0	0
OIA2 - Airfield other paved areas- drains to vegetation	0	0	0	0
86 OIA3 - Light laydown concrete areas- directly connected to drains	0	0	0	0
OIA3 - Light laydown concrete areas - drains to soil	0	0.28	0	0.28
OIA3 - Light laydown concrete areas - drains to vegetation	0	0	0	0
87 OIA4 - Moderate laydown concrete areas - directly connected	0	0.02	0	0.02
OIA4 - Moderate laydown concrete areas - drains to soil	0	0	0	0
OIA4 - Moderate laydown concrete areas - drains to vegetation	0	0	0	0

NBSD OF72 Development Characteristics (continued)

88 OIA5 - Heavy laydown concrete areas- directly connected	0.05	0.07	0	0.11
OIA5 - Heavy laydown concrete areas - drains to soil	0	0	0	0
OIA5 - Heavy laydown concrete areas- drains to vegetation	0	0	0	0
89 OIA6 - Light laydown asphalt areas - directly connected	0	0	0	0
OIA6 - Light laydown asphalt areas- drains to soil	0	0	0	0
OIA6 - Light laydown asphalt areas- drains to vegetation	0	0	0	0
90 OIA7 - Moderate laydown asphalt areas- directly connected	0	0	0	0
OIA7 - Moderate laydown asphalt areas- drains to soil	0	0	0	0
OIA7 - Moderate laydown asphalt areas- drains to vegetation	0	0	0	0
91 OIA8 - Heavy laydown asphalt areas - directly connected	0	0	0	0
OIA8 - Heavy laydown asphalt areas - drains to soil	0	0	0	0
OIA8 - Heavy laydown asphalt areas - drains to vegetation	0	0	0	0
92 OIA9 - Galvanized metal roofs- directly connected	0	0.12	0	0.12
OIA9 - Galvanized metal roofs - drains to soil	0	0	0	0
OIA9 - Galvanized metal roofs- drains to vegetation	0	0	0	0
93 OIA10 - Other galvanized materials- directly connected to drains	0.01	0.55	0	0.57
OIA10 - Other galvanized materials - drains to soil	0.08	0.01	0	0.10
OIA10 - Other galvanized materials - drains to vegetation	0	0	0	0
99 ONPIA11 - Light laydown unpaved - drains to soil	0.05	0	0	0.05

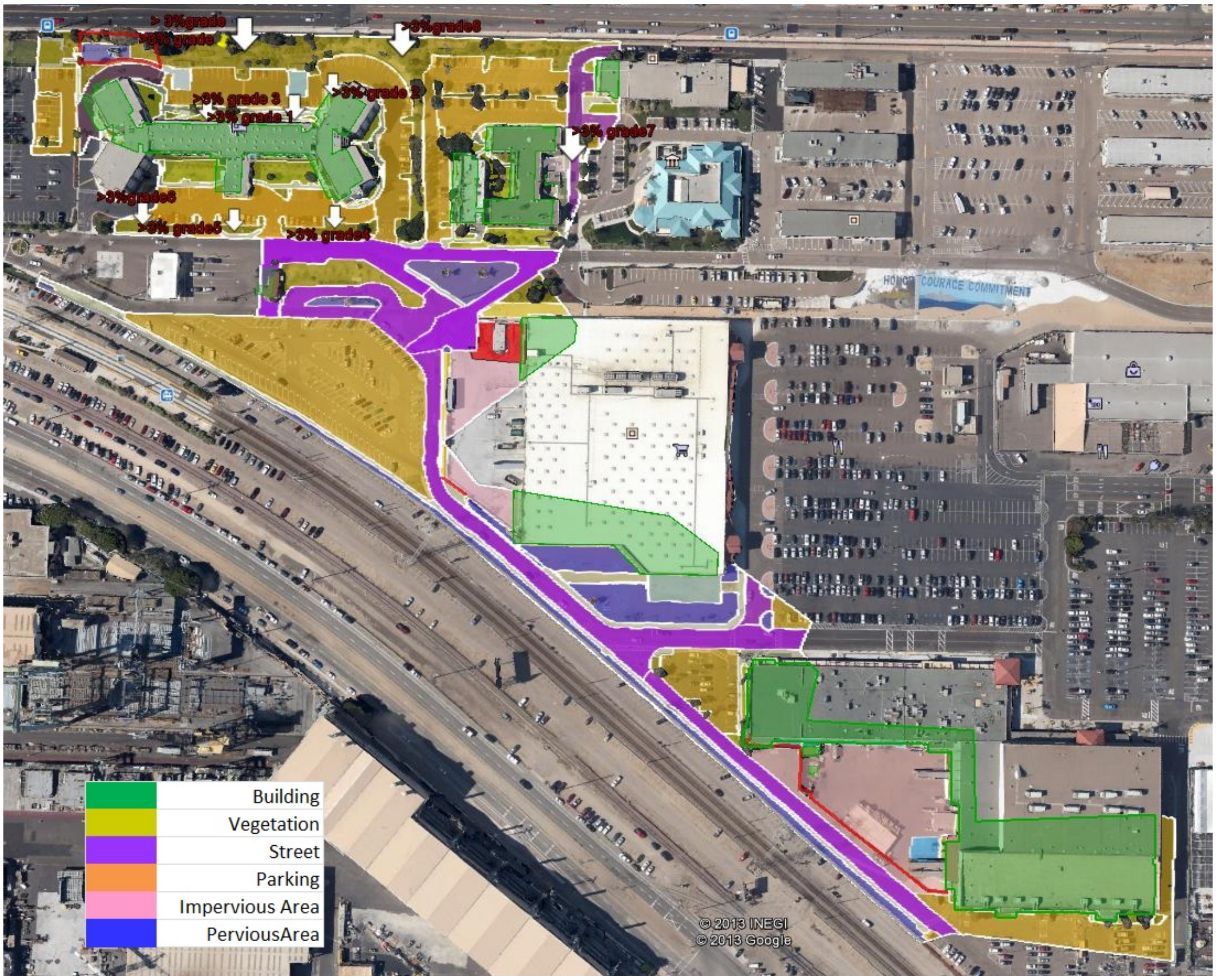
NBSD OF72 Development Characteristics (continued)

99 ONPA11 - Light laydown unpaved - drains to vegetation	0.01	0	0	0.01
100 ONPA12 - Moderate laydown unpaved - drains to soil	0	0	0	0
101 ONPA12 - Moderate laydown unpaved - drains to vegetation	0	0	0	0
102 ONPA13 - Heavy laydown unpaved - drains to soil	0	0	0	0
103 ONPA13 - Heavy laydown unpaved - drains to vegetation	0.15	0	0	0.15
Total Area (acres)	15.53	27.84	1.58	44.94

Outfall 73

Outfall 73 (located adjacent to outfall 72) is comprised of commercial land uses, with buildings, landscaping, parking lots and light to moderate concrete and asphalt covered storage and parking areas. The watershed area for this outfall is approximately 17 acres. This site has pervious areas covering 21% of the total watershed area. An aerial photograph, along with different land use characteristics, is shown in the following figures.

Aerial view and Outline of NBSD Outfall 73



Drainage overview and Land use characterization for NBSD Outfall 73

Photographs taken during site surveys of OF72 and OF73

NBSD OF73 Development Characteristics

	NBSD OF-73				
	Residential	**Commercial**	**Institutional**	**Other Urban**	**Total**
Roofs	**(ac)**	**(ac)**	**(ac)**	**(ac)**	**(ac)**
1 Roofs Flat - directly connected to drains	0	0	0	0	0
2 Roofs Flat - drains to asphalt/concrete	0	1.58	0	0	1.58
3 Roofs Flat - drains to soils	0	0	0	0	0
4 Roofs Flat - drains to vegetation	0	1.09	0	0	1.09
5 Roofs Flat - drains to other surface (artificial turf, rock, gravel, etc.)	0	0.66	0	0	0.66
6 Roofs Pitched - directly connected	0	0	0	0	0
7 Roofs Pitched - drains to asphalt/concrete	0.02	0.00	0	0	0.02
8 Roofs Pitched - drains to soils	0	0	0	0	0
9 Roofs Pitched - drains to vegetation	0	0.00	0	0	0.00
10 Roofs Pitched - drains to other surface (artificial turf, rock, gravel, etc.)	0	0	0	0	0
Parking/Streets/Sidewalks/Driveways					
13 Paved asphalt parking/storage - smooth/intermediate texture - directly connected to drains	0	2.14	0	1.44	3.58
14 Paved asphalt parking/storage - rough/very course texture - directly connected to drains	0	0.67	0.02	0	0.69
15 Paved asphalt parking/storage - drains to pervious	0	0	0	0	0
16 Paved concrete parking/storage - smooth - directly connected	0	0.15	0	0	0.15
17 Paved concrete parking/storage - intermediate - directly connected	0	0	0	0	0
18 Paved concrete parking/storage - drains to pervious	0	0.12	0	0	0.12
19 Unpaved parking/storage - directly connected to drains	0	0	0	0	0
20 Unpaved parking/storage - drains to pervious	0	0	0	0	0
25 Driveways/loading dock -asphalt-directly connected	0	0	0	0	0
26 Driveways/loading dock -concrete-directly connected	0	0	0	0	0
27 Driveways/loading dock - drains to pervious	0	0	0	0	0
31 Sidewalks - directly connected to drains	0	0.98	0	0.27	1.25

NBSD OF73 Development Characteristics (continued)

32 Sidewalks - drains to pervious	0	0.01	0	0	0.01
37 Streets- directly connected to drains	0.06	1.46	0	0.73	2.24
38 Streets-drains to pervious	0	0	0	0	0
Pervious Areas					
45 Landscaping areas - soils	0	0.10	0	0	0.10
46 Landscaping areas - vegetation	0	1.30	0	0.24	1.54
51 Landscaping areas around structures- soils	0	0	0	0	0
52 Landscaping areas around structures - vegetation	0	0.78	0	0	0.78
53 Landscaping areas around structures- other/infiltration area	0	0.45	0	0	0.45
57 Undeveloped areas - soils	0	0	0	0	0
58 Undeveloped areas - vegetation	0	0	0	0	0
71 Other pervious infiltration areas	0	0	0	0.58	0.58
Special Areas					
84 OIA1 - Airfield apron/runway paved areas - directly connected	0	0	0	0	0
OIA1 - Airfield apron/runway paved areas- drains to soil	0	0	0	0	0
OIA1 - Airfield apron/runway paved areas - drains to vegetation	0	0	0	0	0
85 OIA2 - Airfield other paved areas- directly connected	0	0	0	0	0
OIA2 - Airfield other paved areas- drains to soil	0	0	0	0	0
OIA2 - Airfield other paved areas- drains to vegetation	0	0	0	0	0
86 OIA3 - Light laydown concrete areas- directly connected to drains	0	0.16	0	0	0.16
OIA3 - Light laydown concrete areas - drains to soil	0	0	0	0	0
OIA3 - Light laydown concrete areas - drains to vegetation	0	0	0	0	0
87 OIA4 - Moderate laydown concrete areas - directly connected	0	0.33	0	0	0.33
OIA4 - Moderate laydown concrete areas - drains to soil	0	0	0	0	0
OIA4 - Moderate laydown concrete areas - drains to vegetation	0	0	0	0	0

NBSD OF73 Development Characteristics (continued)

88 OIA5 - Heavy laydown concrete areas- directly connected	0	0	0	0	0
OIA5 - Heavy laydown concrete areas - drains to soil	0	0	0	0	0
OIA5 - Heavy laydown concrete areas- drains to vegetation	0	0	0	0	0
89 OIA6 - Light laydown asphalt areas - directly connected	0	1.05	0	0	1.05
OIA6 - Light laydown asphalt areas- drains to soil	0	0	0	0	0
OIA6 - Light laydown asphalt areas- drains to vegetation	0	0	0	0	0
90 OIA7 - Moderate laydown asphalt areas- directly connected	0	0	0	0	0
OIA7 - Moderate laydown asphalt areas- drains to soil	0	0	0	0	0
OIA7 - Moderate laydown asphalt areas- drains to vegetation	0	0	0	0	0
91 OIA8 - Heavy laydown asphalt areas - directly connected	0	0	0	0	0
OIA8 - Heavy laydown asphalt areas - drains to soil	0	0	0	0	0
OIA8 - Heavy laydown asphalt areas - drains to vegetation	0	0	0	0	0
92 OIA9 - Galvanized metal roofs- directly connected	0	0	0	0	0
OIA9 - Galvanized metal roofs - drains to soil	0	0	0	0	0
OIA9 - Galvanized metal roofs- drains to vegetation	0	0	0	0	0
93 OIA10 - Other galvanized materials- directly connected to drains	0	0.14	0	0	0.14
OIA10 - Other galvanized materials - drains to soil	0	0	0	0	0
OIA10 - Other galvanized materials - drains to vegetation	0	0.06	0	0	0.06
99 ONPIA11 - Light laydown unpaved - drains to soil	0	0	0	0	0

NBSD OF73 Development Characteristics (continued)

99 ONPA11 - Light laydown unpaved - drains to vegetation	0	0	0	0	0
100 ONPA12 - Moderate laydown unpaved - drains to soil	0	0	0	0	0
101 ONPA12 - Moderate laydown unpaved - drains to vegetation	0	0	0	0	0
102 ONPA13 - Heavy laydown unpaved - drains to soil	0	0	0	0	0
103 ONPA13 - Heavy laydown unpaved - drains to vegetation	0	0	0	0	0
Total Area (acres)	0.08	13.23	0.02	3.29	16.62

Stormwater Monitoring for Naval Base San Diego (NBSD) – Outfall 51

Outfall	Date Sampled	Dissolved Copper µg/L	Total Copper µg/L	Dissolved Zinc µg/L	Total Zinc µg/L	TSS mg/L	FF/Composite EMC Samples on Same Date	Associated Rain Day/Event	Rain Depth for Monitored Event (inches)
51	02/08/2013	3.1	12.0	6.9	65.8	42.0		2/8/13 16:00 to 2/9/13 8:00	0.27
51	02/19/2013	21.6	255.0	173.0	255.0	316.0		2/19/13 20:00 to 2/19/13 21:00	0.01
51	03/07/2013	70.7	243.0	782.0	1110.0	326.0	FF	3/8/13 6:00 to 3/8/13 22:00	1.02
51	03/07/2013	16.5	82.0	129.0	450.0	133.0	COMP	3/8/13 6:00 to 3/8/13 22:00	1.02

Stormwater Monitoring for Naval Base San Diego (NBSD) – Outfall 70

Outfall	Date Sampled	Dissolved Copper µg/L	Total Copper µg/L	Dissolved Zinc µg/L	Total Zinc µg/L	TSS mg/L	FF/Composite EMC Samples on Same Date	Associated Rain Day/Event	Rain Depth for Monitored Event (inches)
70	1/24/1995		11.0		44.0	62.0		1/23/95 18:00 to 1/24/95 4:00	0.21
70	2/21/1996		49.0		256.0	86.0		2/21/96 10:00 to 2/22/96 1:00	0.13
70	3/13/1996		31.0		138.0	15.0		3/12/96 16:00 to 3/13/96 10:00	0.67
70	02/08/2013	29.0	67.7	38.6	388.0	220.0		2/8/13 16:00 to 2/9/13 8:00	0.27
70	02/19/2013	18.9	62.1	18.3	344.0	183.0		2/19/13 20:00 to 2/19/13 21:00	0.01
70	03/07/2013	31.0	88.5	179.0	433.0	454.0	FF	3/8/13 6:00 to 3/8/13 22:00	1.02
70	03/07/2013	10.2	16.7	102.0	69.4	38.0	COMP	3/8/13 6:00 to 3/8/13 22:00	1.02

Stormwater Monitoring for Naval Base San Diego (NBSD) – Outfall 72

Outfall	Date Sampled	Dissolved Copper µg/L	Total Copper µg/L	Dissolved Zinc µg/L	Total Zinc µg/L	TSS mg/L	FF/Composite EMC Samples on Same Date	Associated Rain Day/Event	Rain Depth for Monitored Event (inches)
72	2/17/1994					15.0		2/17/94 4:00 to 2/17/94 14:00	0.68
72	1/24/1995		83.0			2.0		1/23/95 18:00 to 1/24/95 4:00	0.21
72	4/18/1995		83.0			2.0		4/18/95 4:00 to 4/18/95 14:00	0.37
72	1/21/1996		94.0			29.0		1/21/96 18:00 to 1/21/96 20:00	0.22
72	1/21/1996		57.0					1/21/96 18:00 to 1/21/96 20:00	0.22
72	12/9/1996		42.0			4.0		12/9/96 14:00 to 12/9/96 20:00	0.18
72	1/15/1997		76.2			293.0		1/15/97 17:00 to 1/15/97 20:00	0.19
72	10/27/2000					7.0		10/27/00 6:00 to 10/27/00 10:00	0.31
72	1/8/2001					96.0		1/8/01 11:00 to 1/9/01 5:00	0.65
72	11/24/2001					55.0		11/24/01 17:00 to 11/24/01 19:00	0.22
72	3/7/2002					322.0		3/7/02 6:00 to 3/7/02 10:00	0.02
72	10/11/2012	1110.0	2220.0	1890.0	3470.0	776.0		10/11/12 10:00 to 10/11/12 15:00	0.09
72	02/08/2013	66.3	230.0	290.0	1590.0	169.0	FF	2/8/13 16:00 to 2/9/13 8:00	0.27
72	02/08/2013	74.8	137.0	19.0	484.0	81.0	COMP	2/8/13 16:00 to 2/9/13 8:00	0.27
72	02/19/2013	35.6	120.0	29.7	626.0	196.0	FF	2/19/13 20:00 to 2/19/13 21:00	0.01
72	02/19/2013	34.7	58.0	12.8	148.0	36.5	COMP	2/19/13 20:00 to 2/19/13 21:00	0.01
72	03/07/2013	64.0	112.0	326.0	607.0	77.5	FF	3/8/13 6:00 to 3/8/13 22:00	1.02
72	03/07/2013	37.1	81.6	93.4	192.0	67.0	COMP	3/8/13 6:00 to 3/8/13 22:00	1.02

Stormwater Monitoring for Naval Base San Diego (NBSD) – Outfall 73

Outfall	Date Sampled	Dissolved Copper µg/L	Total Copper µg/L	Dissolved Zinc µg/L	Total Zinc µg/L	TSS mg/L	FF/Composite EMC Samples on Same Date	Associated Rain Day/Event	Rain Depth for Monitored Event (inches)
73	2/17/1994					1.0		2/17/94 4:00 to 2/17/94 14:00	0.68
73	1/24/1995					33.0		1/23/95 18:00 to 1/24/95 4:00	0.21
73	4/18/1995					85.0		4/18/95 4:00 to 4/18/95 14:00	0.37
73	1/21/1996					23.0		1/21/96 18:00 to 1/21/96 20:00	0.22
73	2/21/1996					194.0		2/21/96 10:00 to 2/22/96 1:00	0.13
73	10/11/2012	619.0	3190.0	1890.0	5060.0	1320.0		10/11/12 10:00 to 10/11/12 15:00	0.09
73	02/08/2013	113.0	191.0	146.0	519.0	107.0	FF	2/8/13 16:00 to 2/9/13 8:00	0.27
73	02/08/2013	71.4	198.0	69.5	496.0	90.5	COMP	2/8/13 16:00 to 2/9/13 8:00	0.27
73	02/19/2013	273.0	651.0	93.9	1350.0	21.0	FF	2/19/13 20:00 to 2/19/13 21:00	0.01
73	02/19/2013	48.7	87.3	15.4	168.0	24.0	COMP	2/19/13 20:00 to 2/19/13 21:00	0.01
73	03/07/2013	744.0	967.0	703.0	991.0	117.0		3/8/13 6:00 to 3/8/13 22:00	1.02

First-Flush vs. Composite Stormwater Quality for 2013 San Diego Monitored Sites

The stormwater quality data from the San Diego Naval Base monitoring locations for 2013 were reviewed, comparing TSS, total and dissolved copper, and total and dissolved zinc concentrations obtained during event first flushes to the same event sampled as a whole event composite. Only the dry side sites, summarized below, had these concurrent data; the subase pier monitoring locations did not have these paired data. Only one to three paired sample sets were available for each site, so the following tables list the seven events that had these data from these four locations combined. The seven rain totals ranged from 0.01 to 1.02 (based on the nearby San Diego International Airport rainfall monitoring location). There is insufficient data to compare these relationships for the individual locations. The non-parametric sign test for paired data was used to determine the significance of the observed differences in the concentrations of these paired data groups.

Dry Side 2013 Monitoring Locations at San Diego Naval Base having First Flush and Composite Data

OF51:	High density residential and big box commercial
OF70:	High density residential and big box commercial
OF72:	High density residential (small portion) and big box commercial (mostly)
OF73:	Big box commercial (mostly parking)

The following table shows the paired data for TSS. The first flush concentrations averaged about 3.6 times the composite values, with a moderate significance of 0.06 for the number of sample pairs available. The copper data also have p values of 0.06 with concentrations ratios of about 3.1 and 2.6 for total and dissolved copper, respectively. The total and dissolved zinc paired concentration values had p values of 0.01, with all 7 first flush concentrations greater than the composite concentrations. The concentration ratios were higher than for the copper values, being about 4.1 and 5.3 for total and dissolved zinc respectively.

TSS Data from all 2013 San Diego Monitoring Sites Combined: First Flush vs. Composite Samples

	first flush	composite	FF/comp	rain	OF
	326	133	2.45	1.02	51
	454	38	11.95	1.02	70
	169	81	2.09	0.27	72
	196	36.5	5.37	0.01	72
	77.5	67	1.16	1.02	72
	107	90.5	1.18	0.27	73
	21	24	0.88	0.01	73
number	7	7	7	7	
average	193	67	**3.6**	0.52	
median	169	67	2.1	0.27	
min	21	24	0.9	0.01	
max	454	133	11.9	1.02	
stdev	151	38	4.0	0.48	
COV	0.78	0.57	1.11	0.93	
count increase			6 of 7		
Sign test P			**0.06**		

Total and Dissolved Copper Data from all 2013 San Diego Monitoring Sites Combined: First Flush vs. Composite Samples

	Total Cu						Dissolved Cu				
	first flush	composite	FF/comp	rain	OF		first flush	composite	FF/comp	rain	OF
	243	82	2.96	1.02	51		71	17	4.28	1.02	51
	89	17	5.30	1.02	70		31	10	3.04	1.02	70
	230	137	1.68	0.27	72		66	75	0.89	0.27	72
	120	58	2.07	0.01	72		36	35	1.03	0.01	72
	112	82	1.37	1.02	72		64	37	1.73	1.02	72
	191	198	0.96	0.27	73		113	71	1.58	0.27	73
	651	87	7.46	0.01	73		273	49	5.61	0.01	73
number	7	7	7	7		number	7	7	7	7	
average	234	94	**3.11**	0.52		average	93	42	**2.59**	0.52	
median	191	82	2.07	0.27		median	66	37	1.73	0.27	
min	89	17	0.96	0.01		min	31	10	0.89	0.01	
max	651	198	7.46	1.02		max	273	75	5.61	1.02	
stdev	194	58	2.40	0.48		stdev	84	25	1.79	0.48	
COV	0.83	0.62	0.77	0.93		COV	0.90	0.59	0.69	0.93	
count increase			6 of 7			count increase			6 of 7		
Sign test P			0.06			Sign test P			0.06		

Total and Dissolved Zinc Data from all 2013 San Diego Monitoring Sites Combined: First Flush vs. Composite Samples

	Total Zn						Dissolved Zn				
	first flush	composite	FF/comp	rain	OF		first flush	composite	FF/comp	rain	OF
	1110	450	2.47	1.02	51		782	129	6.06	1.02	51
	433	69	6.24	1.02	70		179	102	1.75	1.02	70
	1590	484	3.29	0.27	72		290	19	15.26	0.27	72
	626	148	4.23	0.01	72		30	13	2.32	0.01	72
	607	192	3.16	1.02	72		326	93	3.49	1.02	72
	519	496	1.05	0.27	73		146	70	2.10	0.27	73
	1350	168	8.04	0.01	73		94	15	6.10	0.01	73
number	7	7	7	7		number	7	7	7	7	
average	891	287	**4.07**	0.52		average	264	63	**5.30**	0.52	
median	626	192	3.29	0.27		median	179	70	3.49	0.27	
min	433	69	1.05	0.01		min	30	13	1.75	0.01	
max	1590	496	8.04	1.02		max	782	129	15.26	1.02	
stdev	456	182	2.37	0.48		stdev	251	48	4.75	0.48	
COV	0.51	0.63	0.58	0.93		COV	0.95	0.75	0.90	0.93	
count increase			7 of 7			count increase			7 of 7		
Sign test P			**0.01**			Sign test P			**0.01**		

Stormwater Quality Variations by Seasons at San Diego Naval Monitoring Locations

Southern California stormwater managers frequently observe significant “seasonal first-flushes” when the initial rains of the year may have larger concentrations compared to other rains later in the rainy season, and may account for much of the total rain year stormwater discharges. The rain year normally starts in the late fall and extends into the spring. The following tables summarize pollutant concentrations at the San Diego Naval Base monitoring locations for October and November compared to the other months, along with non-paired Wilcoxon rank-sum p values comparing the two concentration groups. The first table shows data from the prior Navy WinSLAMM analyses that focused on naval industrial monitoring locations (outfalls 26, 14, 1, 13, and 9) and is only for TSS. The next table is for the current monitoring period sites at the Navy dry side monitoring locations (residential, commercial, and institutional) combined, as there were relatively few data observations for each outfall. Data are shown for TSS, dissolved and total Cu, and dissolved and total Zn. The third table includes the data from the currently monitored subbase pier outfalls for TSS, dissolved and total Cu, and total Zn (dissolved Zn data are not available for this location).

The results for the earlier monitored naval industrial sites do not indicate any significant differences for the TSS data available. The concentration ratios are also not indicative of higher concentrations for the early monitored events (the largest ratio is only 1.18 for TSS at OF1, for example. Outfall 9 had a p value of 0.07, therefore being marginally significant, but the October and November TSS concentrations were much smaller than the later event TSS concentrations. The data for the dry side locations monitored this past year shows that only dissolved zinc had a statistically significant difference between the two data groups, while total copper and total zinc had p values of 0.06 and 0.07 respectively, indicating a marginal level of significance, while also showing much larger concentrations during the early monitoring period compared to later rains. It is likely that several additional rain observations in the early period would result in statistically significant differences for these dry side monitoring locations. The pier monitoring locations during the recent monitoring activities are similar to the previous naval industrial site data; only one condition (TSS) had marginally significantly different concentrations, but the early season data appears to have much lower concentrations than the later season observations.

It is possible that the dry side (residential, commercial, and institutional land uses) have significant seasonal first flush conditions, but additional data would be needed to verify the observations statistically. With so few rain events available in the semi-arid southern California area, these data are difficult to obtain, so the marginally available results may be indicative of this trend reported by others. However, there is no supporting information in the data from the naval industrial data sets supporting seasonal first-flushes from these land uses. It is thought that the highly varying site activities during the different industrial monitoring years caused a greater variability than the seasonal differences, effectively obscuring any seasonal first flush patterns.

Seasonal First Flush TSS Concentrations vs. Other Months for Prior San Diego Naval Base Monitored Sites

	Oct/Nov TSS OF26	other TSS OF26	Oct/Nov TSS OF14	other TSS OF14	Oct/Nov TSS OF1	other TSS OF1	Oct/Nov TSS OF13	other TSS OF13	Oct/Nov TSS OF9	other TSS OF9
count	4	21	5	25	4	14	4	14	2	18
average	159	259	124	184	467	396	550	539	96	352
median	150	176	66	108	268	206	479	324	96	68
min	41	14	5	41	90	61	337	38	23	9
max	294	1,333	362	655	1,243	2,057	904	1,853	170	2,111
stdev	106	323	142	170	536	528	251	561	104	603
COV	0.67	1.25	1.15	0.92	1.15	1.33	0.46	1.04	1.08	1.71
ratio early/other		0.61		0.67		1.18		1.02		0.27
p		0.14		0.22		0.41		0.48		0.07

Seasonal First Flush Concentrations vs. Other Months for 2013 San Diego Residential, Commercial, and Institutional Monitored Sites

	Oct/Nov TSS resid/commer 2013	other months TSS 2013 resid/commer	Oct/Nov Tot Cu 2013 resid/commer	other months Tot Cu 2013 resid/commer	Oct/Nov Dis Cu 2013 resid/commer	other months Dis Cu 2013 resid/commer	Oct/Nov Tot Zn 2013resid/commer	other months Tot Zn 2013resid/commer	Oct/Nov Dis Zn 2013 resid/commer	other months Dis Zinc 2013 resid/commer
count	4	19	2	12	2	6	2	6	2	6
average	540	80	2705	164	865	168	4265	413	1890	152
median	416	37	2705	83	865	60	4265	338	1890	44
min	7	1	2220	42	619	35	3470	148	1890	13
max	1320	322	3190	967	1110	744	5060	991	1890	703
stdev	628	94	686	256	347	282	1124	324	0	272
COV	1.16	1.18	0.25	1.57	0.40	1.68	0.26	0.78	0.00	1.79
ratio early/other		6.77		16.53		5.13		10.32		12.42
p		0.12		0.06		0.12		0.07		<0.001

Seasonal First Flush Concentrations vs. Other Months for 2013 San Diego SubBase Pier Monitored Sites

	Oct/Nov TSS 2013 pier	other months TSS 2013 pier	Oct/Nov Tot Cu 2013 pier	other months Tot Cu 2013 pier	Oct/Nov Dis Cu 2013 pier	other months Dis Cu 2013 pier	Oct/Nov Tot Zn 2013 pier	other months Tot Zn 2013 pier
count	23	73	17	61	3	3	17	61
average	66	177	785	696	114	797	1135	1496
median	44	78	450	380	112	561	710	880
min	6	4	54	37	47	250	138	80
max	240	5260	4080	3610	183	1580	3560	9350
stdev	66	618	973	815	68	696	992	1726
COV	1.01	3.50	1.24	1.17	0.60	0.87	0.87	1.15
ratio early/other		0.37		1.13		0.14		0.76
p		0.07		0.37		0.12		0.14

Norfolk, VA, Naval Facilities

Soil Conditions at Norfolk, VA, Area Naval Facilities

Little Creek

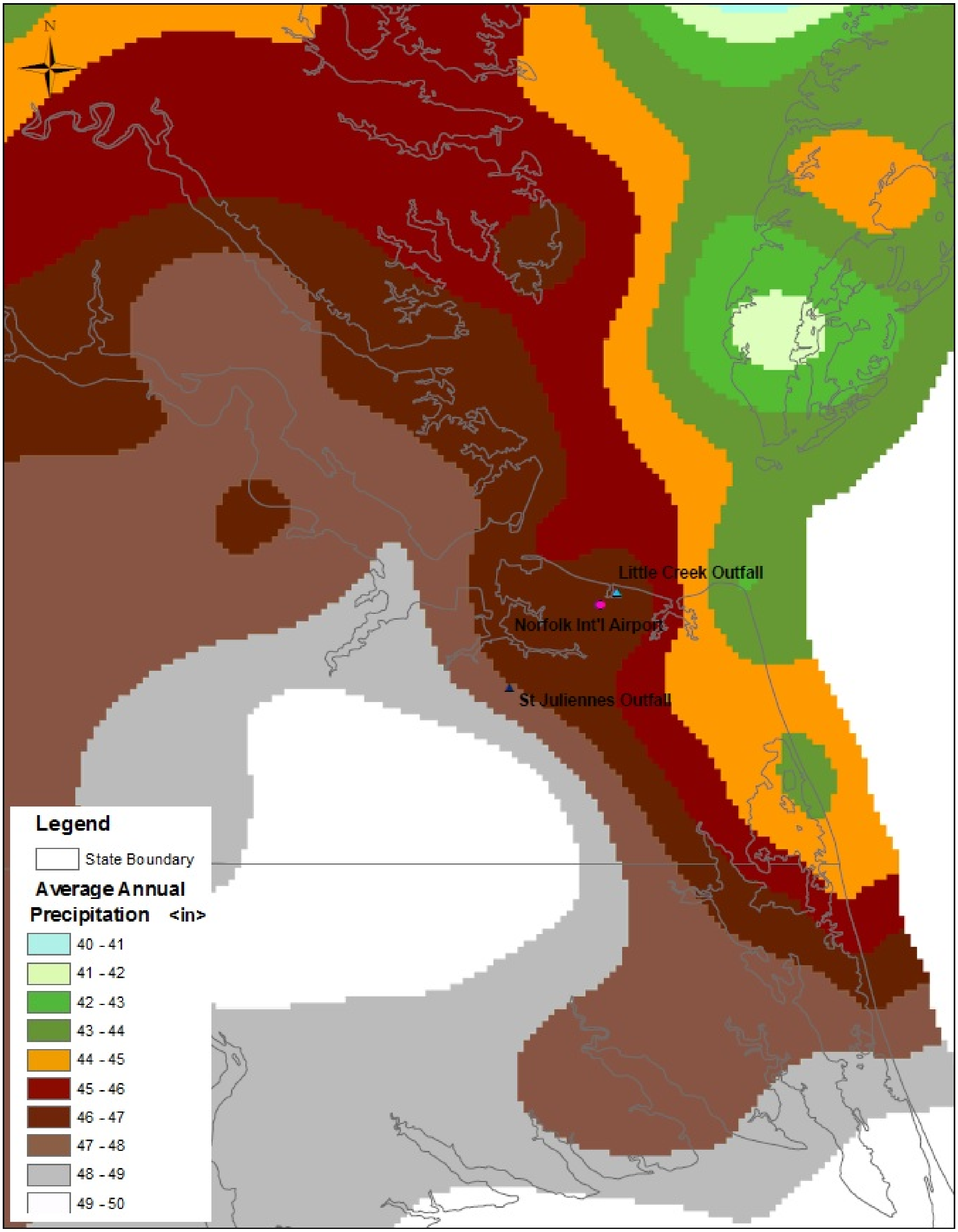
The soils at the Little Creek site are comprised of the Udorthents loamy soil type. Slopes are smooth or irregular, and range from 0 to 25 percent but are dominantly 0 to 5 percent. These soils are slightly darker in the uppermost 6 to 10 inches than in the underlying material, and resemble topsoil. The properties of these soils vary greatly with depth; they are generally well suited for use as building sites. Permeability is moderate to slow to a depth of 10 inches, and rapid to very slow below that depth. However, these soils were heavily compacted and reflect very little infiltration through the soil surface.

St. Juliennes

The soils at the St. Juliennes site are comprised of urban land soils. Typical urban land includes gently sloping areas covered by streets, buildings, parking lots, and other structures that obscure or alter the soils so that identification is not feasible. This site is mostly a scrapyard and storage area and is covered with some pavement, but with much compacted soils that do not provide significant infiltration.

Rain Data for Norfolk, VA Naval Bases

The bases in the Norfolk, VA, study area are located along the shoreline. The following figure shows the locations of these naval bases and the nearby weather station at the Norfolk International Airport, along with the annual average rain depths. The rain variations in this area are also relatively small, although the annual average rain depth is about 46 inches per year.



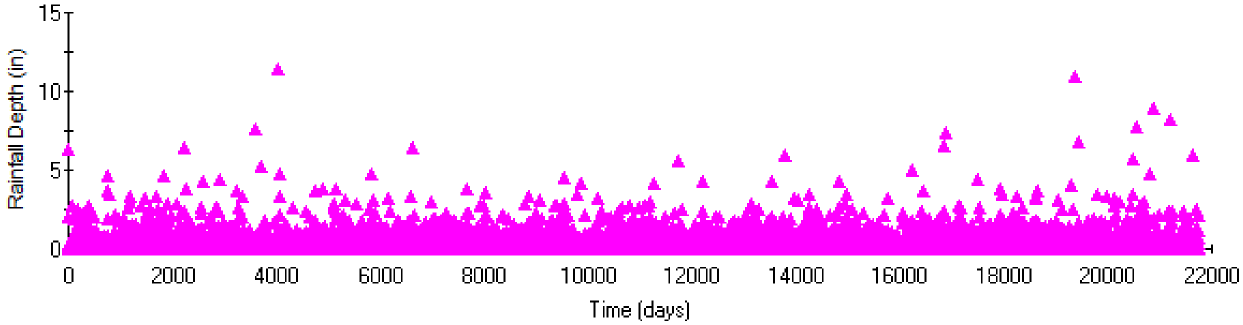
Map of Norfolk, VA, Naval Bases studied and nearby weather stations

NOAA Precipitation Data
Hourly precipitation data is archived by the National Climate Data Center (NCDC) of the National Oceanic and Atmospheric Administration (NOAA) for the Norfolk International Airport. This table shows the approximate range of the historically available data, along with the completeness of the data record, for the airport location.

Stations with Hourly Precipitation Data included for Norfolk, VA, Naval Stations

Station	COOPID	Latitude	Longitude	Data Range	% Completeness
Norfolk International Airport	446139	36.903	-76.192	1948-2012	100

Rainfall Patterns for Norfolk, VA, Naval Bases
The following time series plot shows the rain depths for each rain event that occurred during the period from 1953 to 2013, including the stormwater monitoring period. Most of the Norfolk rains are less than 3 inches, with rare rains greater than 9 or 10 inches.



Norfolk International Airport, VA, rainfall from January 1953 to February 2013

The regional naval facilities and the closest available NOAA rainfall Norfolk airport data are summarized below:

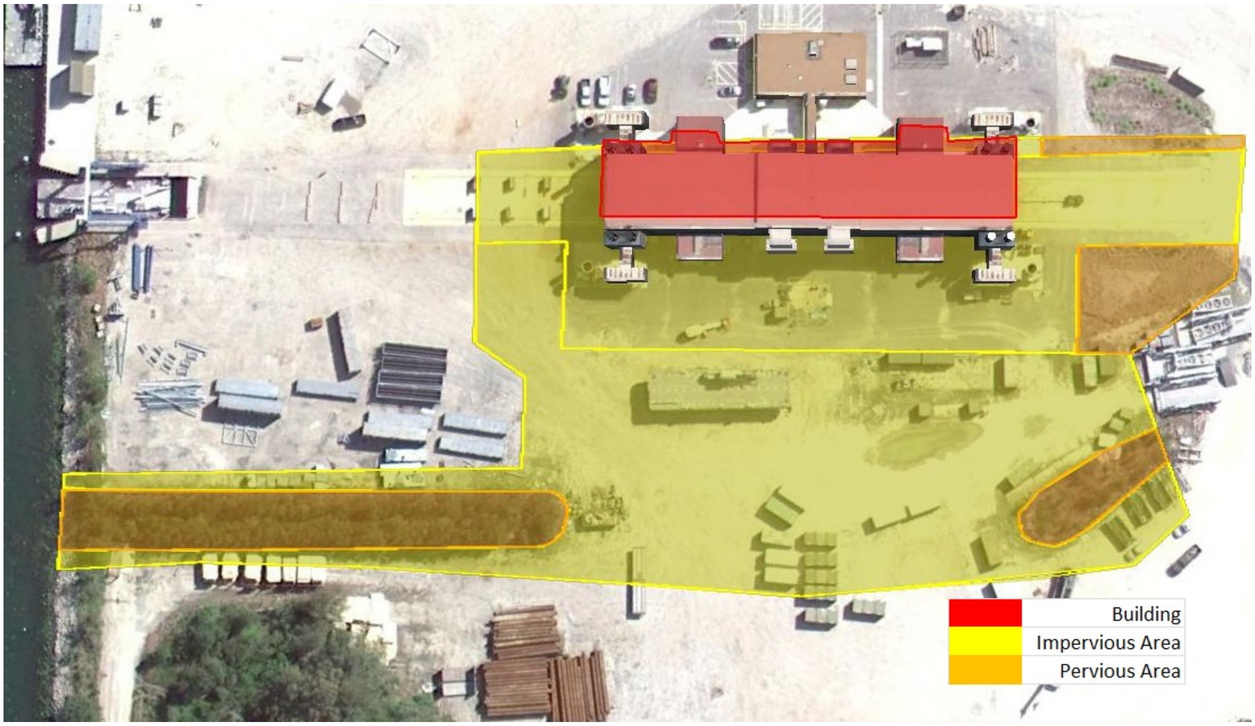
Little Creek: 45 to 50 in/yr (Norfolk International Airport 46 in/yr between 1981 and 2010)
St Juliennes: 45 to 50 in/yr (Norfolk International Airport 46 in/yr between 1981 and 2010)

Therefore, the WinSLAMM calibration efforts will focus on the Norfolk International Airport NOAA data for both the Little Creek and St Juliennes Naval facilities.

Land Development Characteristics at Norfolk, VA, Area Naval Facilities

Naval Amphibious Base Little Creek – Outfall 07

Little Creek Outfall 07 is located in the Naval Amphibious Base Little Creek. A complete data survey is available for this outfall describing the surface coverage and area of each surface type. Outfall 07 is comprised of industrial land use, with buildings and light to moderate laydown concrete and unpaved (but compacted) areas. The watershed area for this outfall is approximately 3 acres. This site has pervious areas accounting for 15% of the total watershed area. An aerial photograph of the watershed is shown in the following figure.



Drainage overview and Land use Characterization for Little Creek Outfall 07


03/27/2013


03/27/2013


03/27/2013


03/27/2013

Photos taken during site survey of Little Creek OF-07

Land Use Development Characteristics for Little Creek OF-07

LANDUSE	**Little Creek OF-07**
Roofs	**Area (ac)**
1 Roofs Flat - directly connected to drains	0
2 Roofs Flat - drains to asphalt/concrete	0
3 Roofs Flat - drains to soils	0
4 Roofs Flat - drains to vegetation	0
5 Roofs Flat - drains to other surface (artificial turf, rock, gravel, etc.)	0
6 Roofs Pitched - directly connected	0
7 Roofs Pitched - drains to asphalt/concrete	0.26
8 Roofs Pitched - drains to soils	0
9 Roofs Pitched - drains to vegetation	0
10 Roofs Pitched - drains to other surface (artificial turf, rock, gravel, etc.)	0
Parking/Streets/Sidewalks/Driveways	
13 Paved asphalt parking/storage - smooth/intermediate texture - directly connected to drains	0
14 Paved asphalt parking/storage - rough/very course texture - directly connected to drains	0
15 Paved asphalt parking/storage - drains to pervious	0

Land Use Development Characteristics for Little Creek OF-07 (continued)

16 Paved concrete parking/storage - smooth - directly connected	0
17 Paved concrete parking/storage - intermediate - directly connected	0
18 Paved concrete parking/storage - drains to pervious	0
19 Unpaved parking/storage - directly connected to drains	0
20 Unpaved parking/storage - drains to pervious	0
25 Driveways/loading dock -asphalt- directly connected	0
26 Driveways/loading dock -concrete- directly connected	0
27 Driveways/loading dock - drains to pervious	0
31 Sidewalks - directly connected to drains	0
32 Sidewalks - drains to pervious	0
37 Streets- directly connected to drains	0
38 Streets-drains to pervious	0
Pervious Areas	
45 Landscaping areas - soils	0
46 Landscaping areas - vegetation	0
51 Landscaping areas around structures- soils	0
52 Landscaping areas around structures - vegetation	0
53 Landscaping areas around structures- other/infiltration area	0
57 Undeveloped areas - soils	0
58 Undeveloped areas - vegetation	0
71 Other pervious infiltration areas	0.46
Special Areas	
84 OIA1 - Airfield apron/runway paved areas - directly connected	0
OIA1 - Airfield apron/runway paved areas- drains to soil	0
OIA1 - Airfield apron/runway paved areas - drains to vegetation	0
85 OIA2 - Airfield other paved areas- directly connected	0
OIA2 - Airfield other paved areas- drains to soil	0
OIA2 - Airfield other paved areas- drains to vegetation	0

Land Use Development Characteristics for Little Creek OF-07 (continued)

86 OIA3 - Light laydown concrete areas- directly connected to drains	0
OIA3 - Light laydown concrete areas - drains to soil	0
OIA3 - Light laydown concrete areas - drains to vegetation	0
87 OIA4 - Moderate laydown concrete areas - directly connected	0.05
OIA4 - Moderate laydown concrete areas - drains to soil	0
OIA4 - Moderate laydown concrete areas - drains to vegetation	0
88 OIA5 - Heavy laydown concrete areas- directly connected	0
OIA5 - Heavy laydown concrete areas - drains to soil	0
OIA5 - Heavy laydown concrete areas- drains to vegetation	0
89 OIA6 - Light laydown asphalt areas - directly connected	0
OIA6 - Light laydown asphalt areas- drains to soil	0
OIA6 - Light laydown asphalt areas- drains to vegetation	0
90 OIA7 - Moderate laydown asphalt areas- directly connected	0
OIA7 - Moderate laydown asphalt areas- drains to soil	0
OIA7 - Moderate laydown asphalt areas- drains to vegetation	0
91 OIA8 - Heavy laydown asphalt areas - directly connected	0
OIA8 - Heavy laydown asphalt areas - drains to soil	0
OIA8 - Heavy laydown asphalt areas - drains to vegetation	0
92 OIA9 - Galvanized metal roofs- directly connected	0
OIA9 - Galvanized metal roofs - drains to soil	0
OIA9 - Galvanized metal roofs- drains to vegetation	0
93 OIA10 - Other galvanized materials- directly connected to drains	0.82
OIA10 - Other galvanized materials - drains to soil	0
OIA10 - Other galvanized materials - drains to vegetation	0

Land Use Development Characteristics for Little Creek OF-07 (continued)

99 ONPIA11 - Light laydown unpaved - drains to soil	0
99 ONPA11 - Light laydown unpaved - drains to vegetation	0
100 ONPA12 - Moderate laydown unpaved - drains to soil	1.42
101 ONPA12 - Moderate laydown unpaved - drains to vegetation	0
102 ONPA13 - Heavy laydown unpaved - drains to soil	0
103 ONPA13 - Heavy laydown unpaved - drains to vegetation	0
Total Area (acres)	3.01

Stormwater Quality at Little Creek Naval Base

Stormwater Monitoring for Little Creek Outfall 07

Quarter	Date	Dissolved Copper (µg/l)	Dissolved Zinc (µg/l)	Associated Rain Day/Event	Rain Depth Associated with Monitored Event (inches)
1st Qtr 2007	2/22/2007	19	98	2/22/07 0:00 to 2/22/07 9:00	0.23
2nd Qtr 2007	6/3/2007	<QL	17	6/3/07 0:00 to 6/4/07 5:00	1.29
3rd Qtr 2007	8/5/2007	8	701	8/5/07 18:00 to 8/6/07 1:00	0.65
4th Qtr 2007	10/24/2007	11	130	10/24/07 12:00 to 10/25/07 20:00	3.41
1st Qtr 2008	1/17/2008	15	3290	1/17/08 8:00 to 1/17/08 23:00	0.6
2nd Qtr 2008	4/4/2008	6	280	4/3/08 16:00 to 4/4/08 3:00	0.59
3rd Qtr 2008	7/23/2008	7	520	7/23/08 13:00 to 7/24/08 3:00	1.78
4th Qtr 2008	11/13/2008	7	307	11/13/08 9:00 to 11/13/08 17:00	1.22
1st Qtr 2009	1/27/2009	11	1440	1/27/09 10:00 to 1/28/09 1:00	0.21

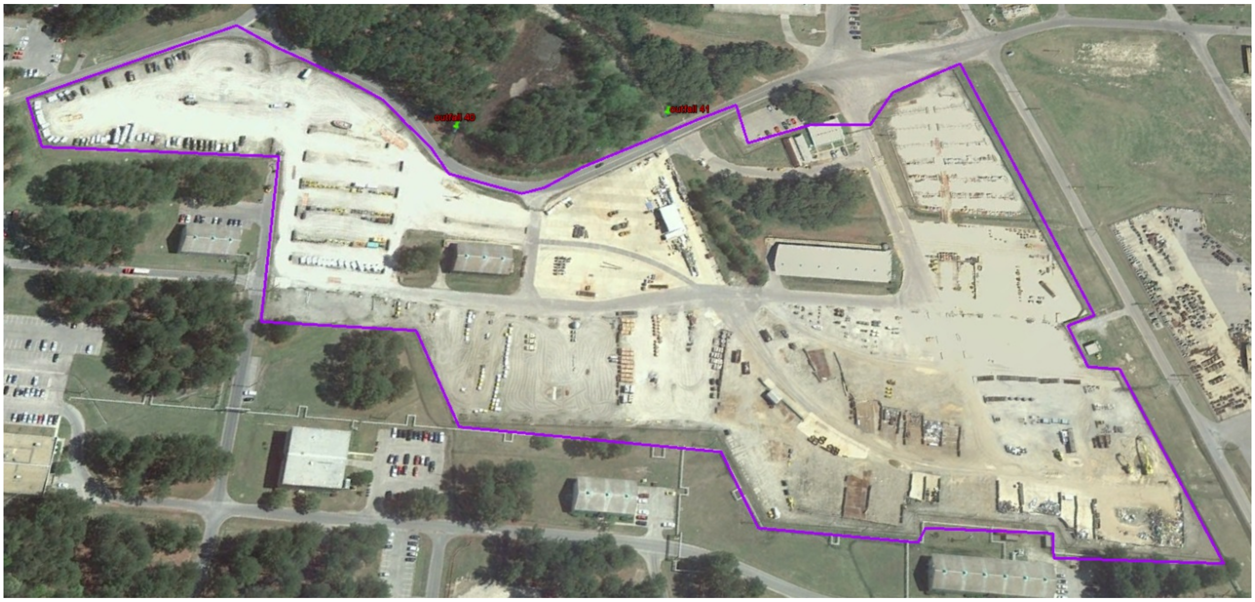
Stormwater Monitoring for Little Creek Outfall 07 (continued)

2nd Qtr 2009	4/20/2009	7	20	4/20/09 13:00 to 4/20/09 18:00	0.85
3rd Qtr 2009	8/4/2009	7	33	8/4/09 12:00 to 8/4/09 13:00	1.68
4th Qtr 2009	11/11/2009	4	31	11/10/09 23:00 to 11/14/09 0:00	7.73
1st Qtr 2010	1/25/2010	4	28	1/25/10 5:00 to 1/25/10 11:00	1.34
2nd Qtr 2010	6/6/2010	9	1160	6/6/10 20:00 to 6/6/10 22:00	0.3
3rd Qtr 2010	8/18/2010	5	56	8/18/10 11:00 to 8/18/10 21:00	1.69
1st Qtr 2011	1/11/2011	10	563	1/11/11 2:00 to 1/11/11 21:00	0.17
2nd Qtr 2011	4/26/2011	10	860	4/26/11 10:00 to 4/26/11 14:00	0.11
3rd Qtr 2011	7/4/2011	5	76	7/4/11 17:00 to 7/4/11 21:00	1.45
4th Qtr 2011	10/19/2011	8	242	10/19/11 0:00 to 10/19/11 5:00	0.74
1st Qtr 2012	1/9/2012	7	198	1/9/12 8:00 to 1/9/12 20:00	0.13
2nd Qtr 2012	4/4/2012	10	1040	4/4/12 20:00 to 4/5/2012 7:00	0.35
3rd Qtr 2012	7/9/2012	9	459	7/9/12 14:00 to 7/9/12 15:00	0.77
4th Qtr 2012	10/7/2012	5	303	10/7/12 4:00 to 10/7/12 21:00	0.49
1st Qtr 2013	2/7/2013	13	489	2/8/13 0:00 to 2/8/13 17:00	2.2

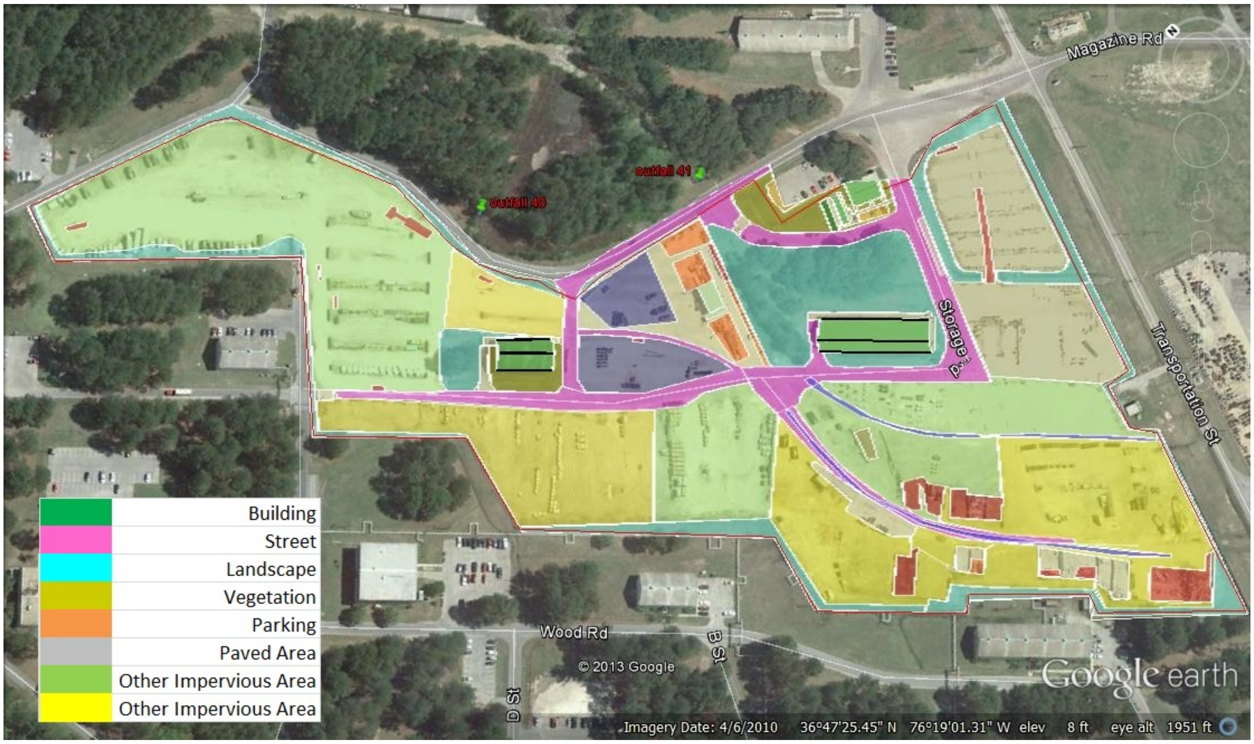
Land Development Characteristics at St. Juliennes Creek Annex

St Juliennes Creek Annex – Outfalls 40 and 41

St Juliennes Outfalls 40 and 41 are located in the St Juliennes Creek Annex. A complete data survey is available for this outfall describing the surface coverage, and area of each surface type. Outfalls 40 and 41 are comprised of industrial land use, with buildings, parking/storage areas, landscaping and light to moderate laydown concrete and unpaved areas. The watershed area for this outfall is approximately 26 acres. This site has pervious area (heavily compacted) accounting to 18% of the total watershed area. An aerial photograph, along with different land use characteristics are shown in the following figures.



Aerial view and Outline of St Juliennes Outfalls 40 and 41



Drainage overview and Land use characterization for St Juliennes Outfalls 40 and 41


03/28/2013


HELI
03/28/2013


06

Photos taken during site surveys of St Juliennes OF 40 and 41

Land Use Development Characteristics for St Juliennes OF 40 & 41

LANDUSE	**St Juliennes OF 40 & 41**
Roofs	**Area (ac)**
1 Roofs Flat - directly connected to drains	0
2 Roofs Flat - drains to asphalt/concrete	0.04
3 Roofs Flat - drains to soils	0.03
4 Roofs Flat - drains to vegetation	0.03
5 Roofs Flat - drains to other surface (artificial turf, rock, gravel, etc.)	0
6 Roofs Pitched - directly connected	0
7 Roofs Pitched - drains to asphalt/concrete	0.24
8 Roofs Pitched - drains to soils	0
9 Roofs Pitched - drains to vegetation	0.20
10 Roofs Pitched - drains to other surface (artificial turf, rock, gravel, etc.)	0
Parking/Streets/Sidewalks/Driveways	
13 Paved asphalt parking/storage - smooth/intermediate texture - directly connected to drains	0
14 Paved asphalt parking/storage - rough/very course texture - directly connected to drains	0.35
15 Paved asphalt parking/storage - drains to pervious	0
16 Paved concrete parking/storage - smooth - directly connected	0.01
17 Paved concrete parking/storage - intermediate - directly connected	0.05
18 Paved concrete parking/storage - drains to pervious	2.42

Land Use Development Characteristics for St Juliennes OF 40 & 41 (continued)

19 Unpaved parking/storage - directly connected to drains	0
20 Unpaved parking/storage - drains to pervious	0
25 Driveways/loading dock -asphalt- directly connected	0
26 Driveways/loading dock -concrete- directly connected	0
27 Driveways/loading dock - drains to pervious	0.10
31 Sidewalks - directly connected to drains	0
32 Sidewalks - drains to pervious	0.02
37 Streets- directly connected to drains	2.33
38 Streets-drains to pervious	0
Pervious Areas	
45 Landscaping areas - soils	0
46 Landscaping areas - vegetation	4.10
51 Landscaping areas around structures- soils	0.02
52 Landscaping areas around structures - vegetation	0.44
53 Landscaping areas around structures- other/infiltration area	0
57 Undeveloped areas - soils	0
58 Undeveloped areas - vegetation	0
71 Other pervious infiltration areas	0
Special Areas	
84 OIA1 - Airfield apron/runway paved areas - directly connected	0
OIA1 - Airfield apron/runway paved areas- drains to soil	0
OIA1 - Airfield apron/runway paved areas - drains to vegetation	0
85 OIA2 - Airfield other paved areas- directly connected	0
OIA2 - Airfield other paved areas- drains to soil	0
OIA2 - Airfield other paved areas- drains to vegetation	0
86 OIA3 - Light laydown concrete areas- directly connected to drains	0.92
OIA3 - Light laydown concrete areas - drains to soil	0
OIA3 - Light laydown concrete areas - drains to vegetation	0

Land Use Development Characteristics for St Juliennes OF 40 & 41 (continued)

87 OIA4 - Moderate laydown concrete areas - directly connected	0.13
OIA4 - Moderate laydown concrete areas - drains to soil	0
OIA4 - Moderate laydown concrete areas - drains to vegetation	0
88 OIA5 - Heavy laydown concrete areas- directly connected	0
OIA5 - Heavy laydown concrete areas - drains to soil	0
OIA5 - Heavy laydown concrete areas- drains to vegetation	0
89 OIA6 - Light laydown asphalt areas - directly connected	0
OIA6 - Light laydown asphalt areas- drains to soil	0
OIA6 - Light laydown asphalt areas- drains to vegetation	0
90 OIA7 - Moderate laydown asphalt areas- directly connected	0
OIA7 - Moderate laydown asphalt areas- drains to soil	0
OIA7 - Moderate laydown asphalt areas- drains to vegetation	0
91 OIA8 - Heavy laydown asphalt areas - directly connected	0
OIA8 - Heavy laydown asphalt areas - drains to soil	0
OIA8 - Heavy laydown asphalt areas - drains to vegetation	0
92 OIA9 - Galvanized metal roofs- directly connected	0
OIA9 - Galvanized metal roofs - drains to soil	0
OIA9 - Galvanized metal roofs- drains to vegetation	0
93 OIA10 - Other galvanized materials- directly connected to drains	0
OIA10 - Other galvanized materials - drains to soil	2.31
OIA10 - Other galvanized materials - drains to vegetation	0
99 ONPIA11 - Light laydown unpaved - drains to soil	0
99 ONPA11 - Light laydown unpaved - drains to vegetation	5.04

Land Use Development Characteristics for St Juliennes OF 40 & 41 (continued)

100 ONPA12 - Moderate laydown unpaved - drains to soil	6.74
101 ONPA12 - Moderate laydown unpaved - drains to vegetation	0
102 ONPA13 - Heavy laydown unpaved - drains to soil	0
103 ONPA13 - Heavy laydown unpaved - drains to vegetation	0
Total Area (acres)	25.52

Stormwater Quality at St. Juliennes Annex Naval Facility

Stormwater Monitoring for St Juliennes Outfalls 40 & 41

Date	Total Recoverable Copper µg/L	Total Recoverable Zinc µg/L	TSS mg/L	Associated Rain Day/Event	Rain Depth Associated with Monitored Event (inches)
OUTFALL 040					
Dec. 31, 2009	8	42	22	12/31/09 2:00 to 12/31/09 8:00	0.51
Sept. 3, 2010	15	49	8.5	9/3/10 4:00 to 9/3/10 12:00	0.21
Jul. 4, 2011	58	106	11	7/4/11 17:00 to 7/4/11 21:00	1.45
Dec. 16, 2012	28	91	47	12/16/12 5:00 to 12/16/12 14:00	0.59
OUTFALL 041					
Jan. 08, 2007	12	109	22	1/8/07 6:00 to 1/9/07 10:00	0.85
Mar. 30, 2008	40	193	11	3/30/08 9:00 to 3/30/08 18:00	0.3
Apr. 6 2009	8	46	11	4/6/09 7:00 to 6/6/09 14:00	0.46

Northwest Naval Bases

Soil Conditions at Northwest Naval Bases

Bangor

According to the USDA web soil survey, the soils at the Bangor site are of the Alderwood-Harstine soil type. These soils are moderately deep and moderately well drained. Typically, the surface of Alderwood soils is covered by a thin mat of undecomposed needles and wood fragments. The subsurface layers are very gravelly sandy loam. The subsoil is very gravelly loam. The substratum is gravelly sandy loam glacial till that is weakly-silica-cemented in the upper part. Depth to this hardpan ranges from 20 to 40 inches. Typically, the surface of Harstine soils is covered by a thin mat of undecomposed needles and wood fragments. The surface layer and subsoil are gravelly sandy loam. The substratum is weakly-silica-cemented gravelly loamy sand over weakly-cemented compact glacial till. Depth to the hardpan ranges from 25 to 40 inches. The soils can be severely compacted with very low infiltration rates in developed areas due to building construction or activities.

Bremerton

The soils in the Bremerton site are comprised of the following soil types: Alderwood very gravelly sandy loam, 6 to 15 % slopes (18.5%), Alderwood very gravelly sandy loam, 15 to 30 % slopes (22.1%), Neilton gravelly loamy sand, 0 to 3 % slopes (44.9%), and Urban land-Alderwood complex, 0 to 8 % slopes (14.5%). The soils can be severely compacted with very low infiltration rates in developed areas due to building construction or activities. These soil types are described by the USDA web soil survey:

Alderwood very gravelly sandy loam, 6 to 15% slopes: These soils are moderately deep and moderately well drained. Typically, the surface of this soil is covered by a mat of undecomposed needles and wood fragments. The subsurface layer is brown very gravelly sandy loam 1/2 inch thick. The subsoil is brown very gravelly loam about 21 inches thick. The substratum to a depth of 60 inches or more is grayish brown gravelly sandy loam that is weakly-silica-cemented in the upper part. Depth to the silica-cemented hardpan ranges from 20 to 40 inches. Permeability of this Alderwood soil is moderately rapid above the hardpan and very slow in the hardpan layer.

Alderwood very gravelly sandy loam, 15 to 30% slopes: These soils are steeper, otherwise, they are similar to the milder sloped Alderwood soils descried above.

Neilton gravelly loamy sand, 0 to 3% slopes: These soils are deep and excessively drained. Typically, the surface layer is dark brown gravelly loamy sand about 4 inches thick. The subsoil is brown very gravelly loamy sand about 15 inches thick. The substratum to a depth of 60 inches is very gravelly sand. Permeability of this Neilton soil is rapid to a depth of 19 inches and very rapid in the substratum.

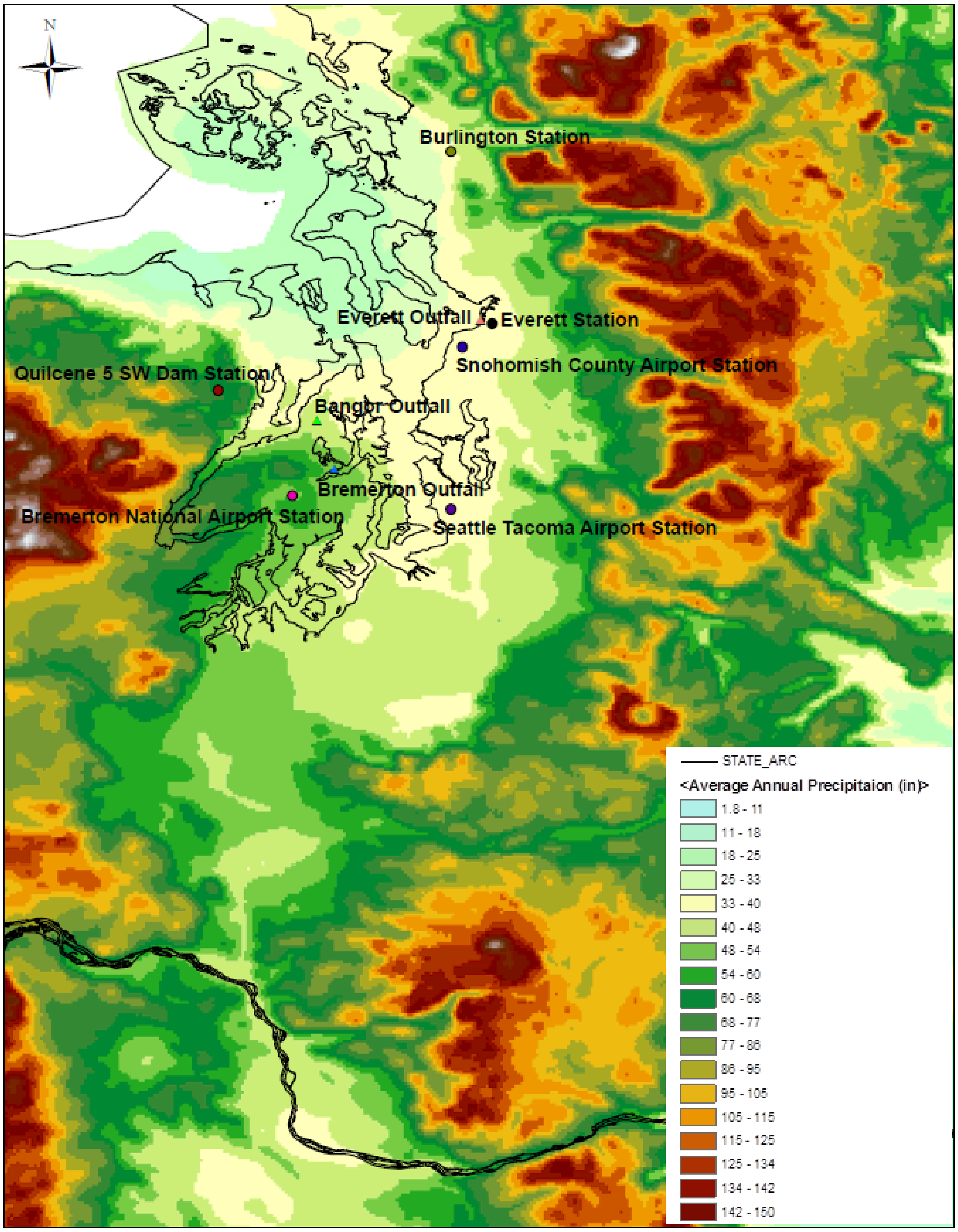
Urban land-Alderwood complex, 0 to 8% slopes: These soils are moderately well drained and exist on beaches and low terraces on broad uplands. This complex is about 70 percent urban land and 20 percent Alderwood very gravelly sandy loam, 0 to 8 percent slopes. The components of this complex are so intricately intermingled that it was not practical to map them separately at the scale used. The Alderwood soil is moderately deep and moderately well drained. Typically, the surface of this soil is covered by a thin mat of undecomposed needles and wood fragments. The subsurface layer is brown very gravelly sandy loam about 0.5 inches thick. The subsoil is brown very gravelly loam about 21 inches thick. The substratum to a depth of 60 inches or more is grayish brown gravelly sandy loam that is weakly-silica-cemented in the upper part. Depth to the silica-cemented hardpan ranges from 20 to 40 inches. Permeability of this Alderwood soil is moderately rapid above the hardpan and very slow in the hardpan.

Everett

The soils in Everett site are comprised of the urban land soil type. Typical urban land includes gently sloping areas covered by streets, buildings, parking lots, and other structures that obscure or alter the soils so that identification is not feasible. The urban soils can be severely compacted with very low infiltration rates in developed areas due to building construction or activities.

Rain Data for Northwest Naval Bases

The bases in the northwest study area examined this year are located along the shores and islands of Puget Sound, Washington. An important part of the model calibration process relies on using rainfall data for each site that correlates with the samples collected at each outfall. This section summarizes the available data for each naval base and the associated weather stations. The following figure shows the locations for the naval bases and the nearby weather stations in the northwest study area, along with the annual average rain depth variations in the region.



Map of Naval Bases and nearby weather stations

NOAA Precipitation Data

Hourly precipitation data is archived by the National Climate Data Center (NCDC) of the National Oceanic and Atmospheric Administration (NOAA). The weather stations are generally operated by the U.S. National Weather Service (NWS), the Federal Aviation Administration (FFA), or by cooperative stations in the U.S. and its territories. The following table is a list of the weather stations near the northwestern naval bases that have hourly rainfall data, as supplied on the most recent EarthInfo CDs (Santa Monica, CA), a commercial supplier of nationwide NOAA weather information. These weather stations in the Puget Sound area are shown on the preceding map. The following table shows the approximate range of historical data available for each site, along with the completeness of the data record. The most comprehensive data sets are for Quilcene, Everett, Burlington, and the Seattle Tacoma International Airport (SEATAC) as shown on the following table.

Stations with Hourly Precipitation Data included for Northwest Naval Stations

Station	COOPID	Latitude	Longitude	Data Range	% Completeness
Quilcene 5 SW Dam WS	456851	47.784	-122.979	1948-2012	89
Everett WS	452675	47.975	-122.195	1948-2012	91
Burlington WS	450986	48.467	-122.313	1948-2012	91
Seattle Tacoma AP WS	457473	47.444	-122.313	1948-2012	99

Global Historical Climatological Network

Besides the basic NOAA data shown above, additional rainfall data for the region were also investigated that were located closer to the naval bases studied. Data from the Global Historical Climatological Network (GHCN) is also archived by the National Climate Data Center (NCDC). These weather stations are comprised of a worldwide network of weather stations (approximately 20,000 stations). Numerous organizations such as the Automated Weather Network (AWN), Global Telecommunications System (GTS), and the Automated Surface Observing System (ASOS), participate in this effort. Stations geographically close to each naval station are included in the following table along with the historical data range for each site.

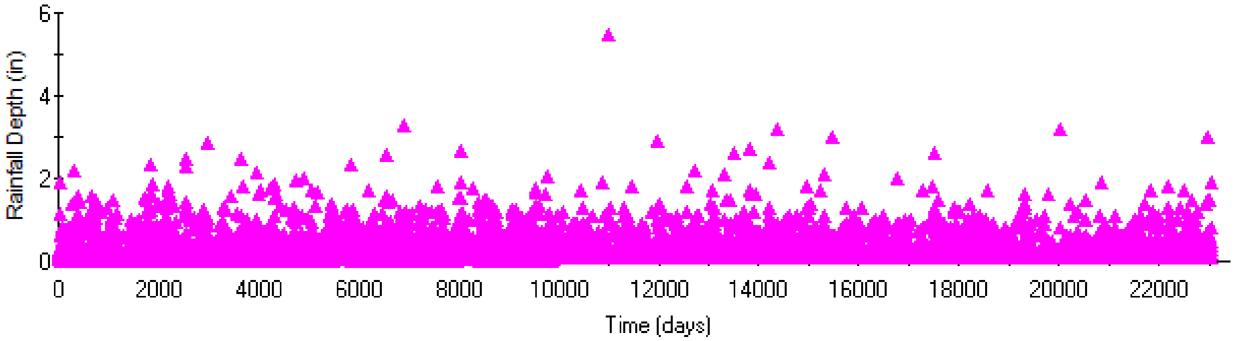
Stations with GHCN Precipitation Data included for Northwest Naval Stations

Station	Station Owner	Latitude	Longitude	Data Range
Bremerton National AP	Bremerton National Airport	47.483	-122.767	1973-2013
Snohomish County AP	Snohomish County Airport	47.908	-122.28	2006-2013

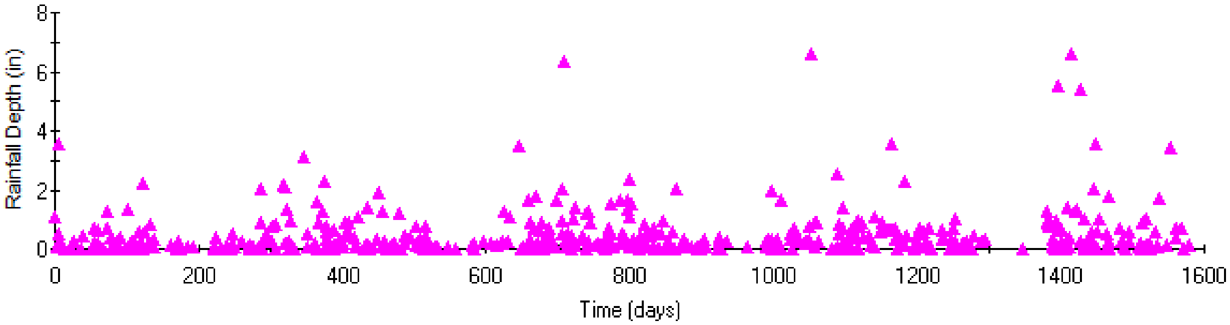
Data for these locations were obtained through the NOAA website. These data required substantial reformatting for the analyses and modeling efforts.

Rainfall Patterns for Northwest Naval Bases

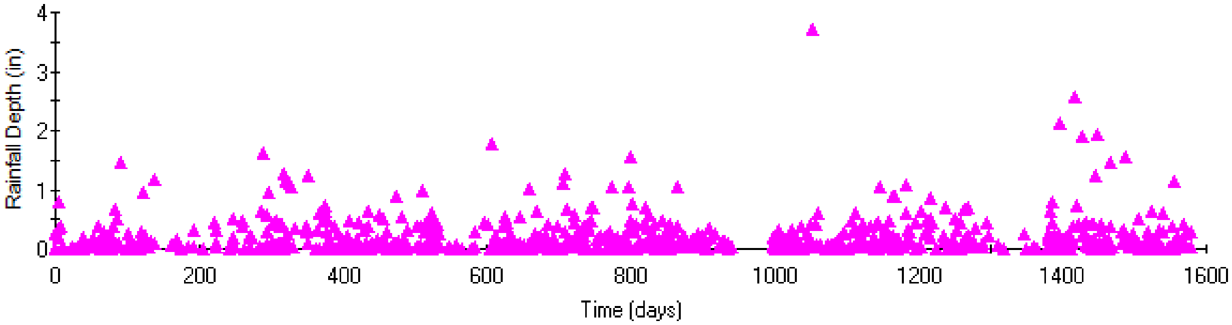
The following three figures are time series plots showing the rain depths for each rain event that occurred during the period corresponding to the stormwater monitoring dates. Everett and Snohomish are quite similar, with most of the rains less than one inch, with occasional rains as large as 4 or 5 inches. The Bremerton rains are much larger, with most rains less than about 2 inches and rare rains in the 6 to 8 inch category.



Everett, WA, rainfall from January 1949 to February 2012



Bremerton National AP, WA, rainfall from January 2009 to April 2013



Snohomish County AP, WA, rainfall from January 2009 to April 2013

The regional naval facilities and the closest available NOAA rainfall data are summarized below:

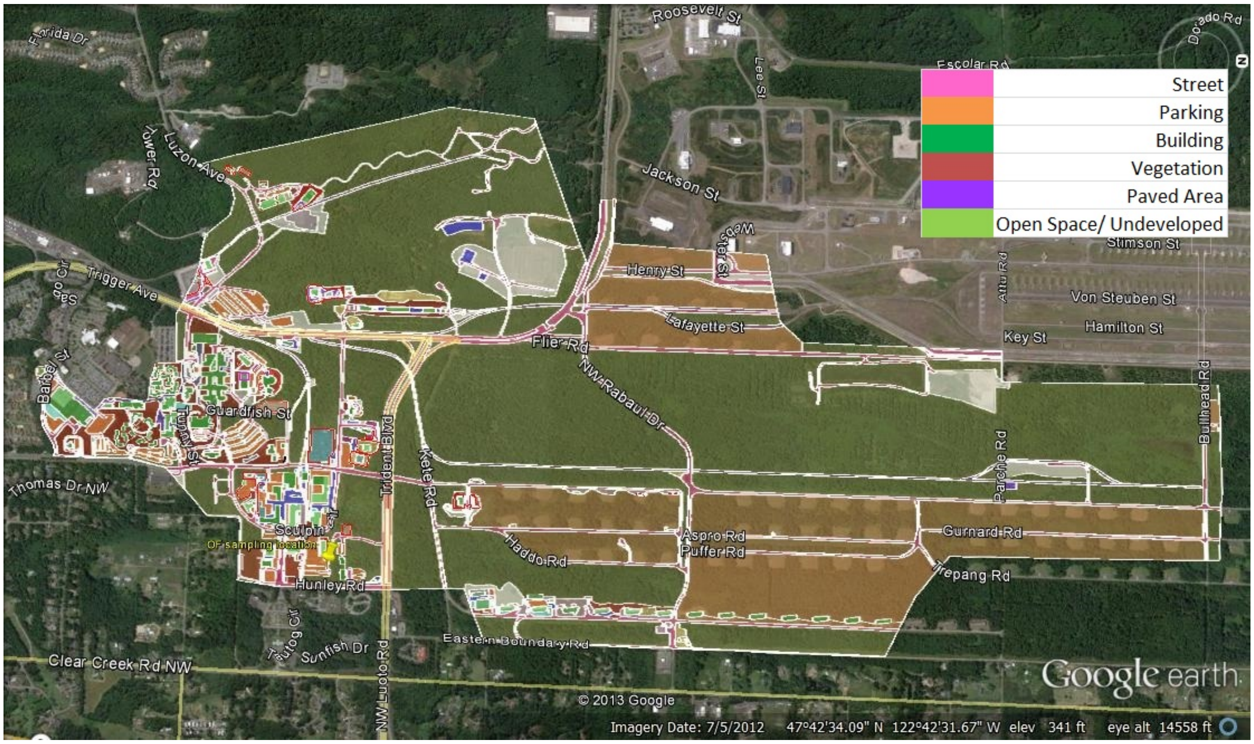
Bangor: 40 to 48 in/yr (Bremerton 53 in/yr between 1981 and 2010)
Bremerton: 48 to 54 in/yr (Bremerton 53 in/yr between 1981 and 2010)
Everett: 33 to 40 in/yr (Everett 36 in/yr between 1981 and 2010, and Snohomish 34 in/yr between 1981 and 2010)

The WinSLAMM calibration efforts will therefore focus on the Bremerton NOAA data for Bangor and Bremerton Naval facilities, and Everett for the Everett Naval facility.

Land Development Characteristics at Bangor Trident Base

Bangor Trident Base - Outfall 02

Bangor Outfall 02 is located at the Bangor Trident Base. A complete data survey is available for this outfall describing the surface coverage and area of each surface type. Outfall 02 is comprised of commercial, industrial and institutional land uses, with buildings, landscaping, and light to moderate laydown concrete, asphalt and unpaved areas. The watershed area for this outfall is approximately 1,442 acres. There is a temporary sewage lagoon located within the site. This site has a large amount of pervious areas accounting for 82% of the total watershed area. An aerial photograph, along with different land use characteristics, is shown in the following figures.



Drainage overview and Land use characterization for Bangor Outfall 02


04/10/2013


NO SMOKING
04/10/2013


04/10/2013


04/10/2013


BLDG 7450
T-794
04/10/2013


KEEP BACK 100 FT

Photos taken during site survey at Bangor OF02

Land Use Development Characteristics for Bangor OF 02

LANDUSE	**Bangor OF- 02**
Roofs	**Area (ac)**
1 Roofs Flat - directly connected to drains	12.23
2 Roofs Flat - drains to asphalt/concrete	2.60
3 Roofs Flat - drains to soils	0.14
4 Roofs Flat - drains to vegetation	1.20
5 Roofs Flat - drains to other surface (artificial turf, rock, gravel, etc.)	0.44
6 Roofs Pitched - directly connected	8.27
7 Roofs Pitched - drains to asphalt/concrete	5.16
8 Roofs Pitched - drains to soils	0.79
9 Roofs Pitched - drains to vegetation	2.01
10 Roofs Pitched - drains to other surface (artificial turf, rock, gravel, etc.)	0.77
Parking/Streets/Sidewalks/Driveways	
13 Paved asphalt parking/storage - smooth/intermediate texture - directly connected to drains	14.74
14 Paved asphalt parking/storage - rough/very course texture - directly connected to drains	6.63
15 Paved asphalt parking/storage - drains to pervious	19.46
16 Paved concrete parking/storage - smooth - directly connected	0.63
17 Paved concrete parking/storage - intermediate - directly connected	0.18
18 Paved concrete parking/storage - drains to pervious	1.80
19 Unpaved parking/storage - directly connected to drains	0.03
20 Unpaved parking/storage - drains to pervious	2.35
25 Driveways/loading dock -asphalt- directly connected	1.76
26 Driveways/loading dock -concrete- directly connected	0.47
27 Driveways/loading dock - drains to pervious	1.23
31 Sidewalks - directly connected to drains	1.19
32 Sidewalks - drains to pervious	0.58
37 Streets- directly connected to drains	100.36
38 Streets-drains to pervious	45.61

Land Use Development Characteristics for Bangor OF 02 (continued)

Pervious Areas	
45 Landscaping areas - soils	28.49
46 Landscaping areas - vegetation	43.53
51 Landscaping areas around structures- soils	0
52 Landscaping areas around structures - vegetation	48.69
53 Landscaping areas around structures- other/infiltration area	0.45
57 Undeveloped areas - soils	0
58 Undeveloped areas - vegetation	795.39
71 Other pervious infiltration areas	269.71
Special Areas	
84 OIA1 - Airfield apron/runway paved areas - directly connected	0
OIA1 - Airfield apron/runway paved areas- drains to soil	0
OIA1 - Airfield apron/runway paved areas - drains to vegetation	0
85 OIA2 - Airfield other paved areas- directly connected	0
OIA2 - Airfield other paved areas- drains to soil	0
OIA2 - Airfield other paved areas- drains to vegetation	0
86 OIA3 - Light laydown concrete areas- directly connected to drains	0.14
OIA3 - Light laydown concrete areas - drains to soil	0
OIA3 - Light laydown concrete areas - drains to vegetation	0.26
87 OIA4 - Moderate laydown concrete areas - directly connected	3.53
OIA4 - Moderate laydown concrete areas - drains to soil	0.21
OIA4 - Moderate laydown concrete areas - drains to vegetation	0
88 OIA5 - Heavy laydown concrete areas- directly connected	0
OIA5 - Heavy laydown concrete areas - drains to soil	0
OIA5 - Heavy laydown concrete areas- drains to vegetation	0

Land Use Development Characteristics for Bangor OF 02 (continued)

89 OIA6 - Light laydown asphalt areas - directly connected	7.20
OIA6 - Light laydown asphalt areas- drains to soil	0.06
OIA6 - Light laydown asphalt areas- drains to vegetation	1.84
90 OIA7 - Moderate laydown asphalt areas- directly connected	0
OIA7 - Moderate laydown asphalt areas- drains to soil	0
OIA7 - Moderate laydown asphalt areas- drains to vegetation	0.12
91 OIA8 - Heavy laydown asphalt areas - directly connected	0.83
OIA8 - Heavy laydown asphalt areas - drains to soil	0.41
OIA8 - Heavy laydown asphalt areas - drains to vegetation	0
92 OIA9 - Galvanized metal roofs- directly connected	0
OIA9 - Galvanized metal roofs - drains to soil	0
OIA9 - Galvanized metal roofs- drains to vegetation	0
93 OIA10 - Other galvanized materials- directly connected to drains	0
OIA10 - Other galvanized materials - drains to soil	0
OIA10 - Other galvanized materials - drains to vegetation	2.29
99 ONPIA11 - Light laydown unpaved - drains to soil	0.64
99 ONPA11 - Light laydown unpaved - drains to vegetation	6.79
100 ONPA12 - Moderate laydown unpaved - drains to soil	0
101 ONPA12 - Moderate laydown unpaved - drains to vegetation	0.33
102 ONPA13 - Heavy laydown unpaved - drains to soil	0
103 ONPA13 - Heavy laydown unpaved - drains to vegetation	0.66
Total Area (acres)	1442.17

Stormwater Quality at Bangor Trident Base

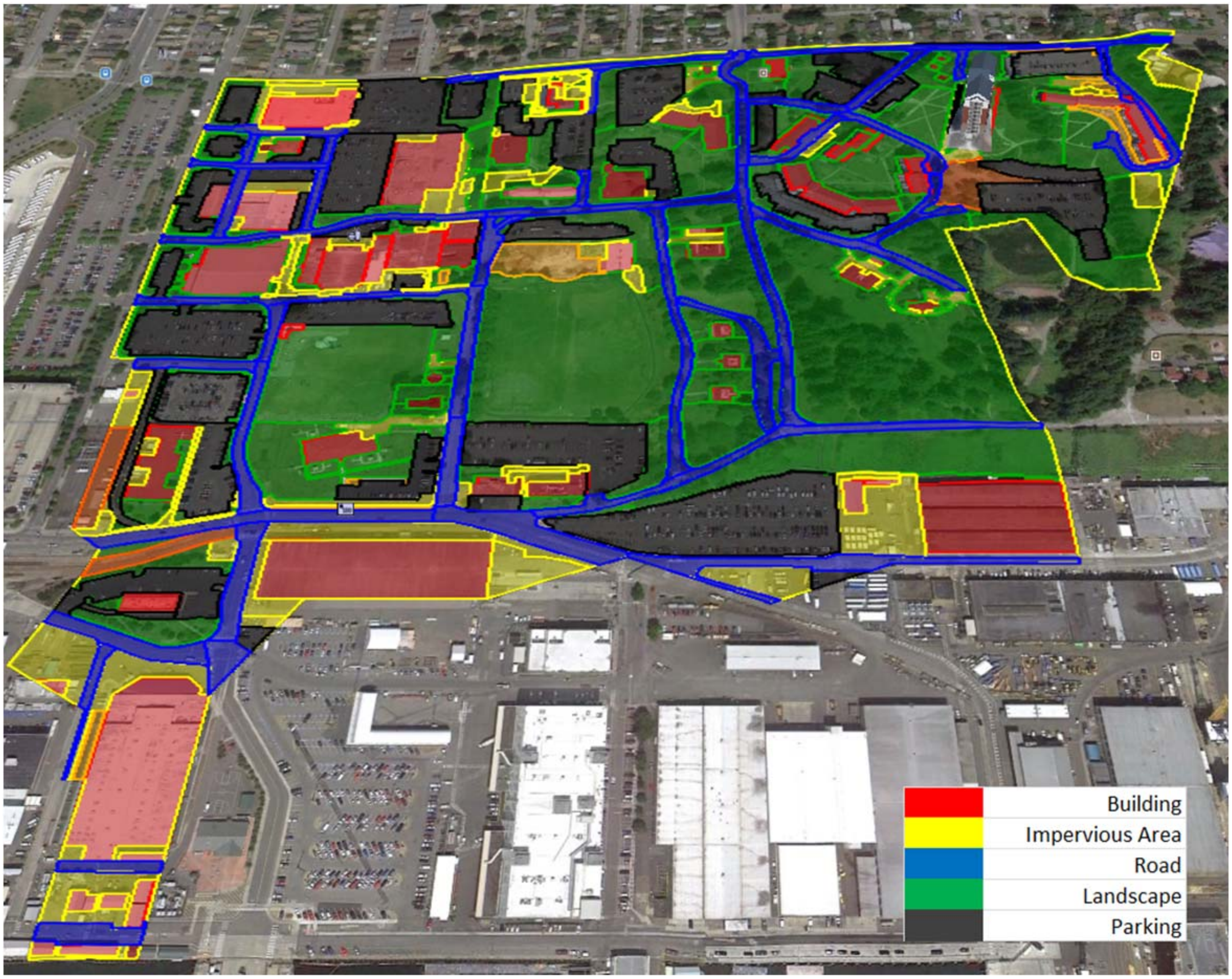
Stormwater Monitoring for Bangor Outfall 02

Date	Copper (μg/L)	Zinc (μg/L)	TSS (mg/L)	Associated Rain Day/Event	Rain Depth Associated with Monitored Event (inches)
5 Nov 09	2.48	14.00	<4.0	11/5/09 15:00 to 11/6/09 2:00	0.82
11 Mar 10	3.30	30.70	5	3/11/10 8:00 to 3/12/10 22:00	1.41
10 May 10	3.7	15.6	<4.0	5/10/10 9:00 to 5/10/10 14:00	0.36
31 Aug 10	<3.0	<4.0	13	8/31/10 12:00 to 8/31/10 23:00	0.17
4 Qtr Avg	2.75	15.58	5.50		
22 Sep 11	0.28	4.79		9/22/11 7:00 to 9/22/11 20:00	0.3
21 Oct 11	3.94	10.90		10/21/11 17:00 to 10/22/11 0:00	0.29
21 Nov 11	13.70	30.80		11/21/11 12:00 to 11/23/11 14:00	6.61
27 Dec 11	22.5	10.9		12/27/11 0:00 to 12/28/11 12:00	2.54
4 Jan 12	9.15	22.6		1/3/12 21:00 to 1/4/12 02:00	0.17
13 Feb 12	7.93	50.0		2/13/12 5:00 to 2/13/12 14:00	0.16
5 Mar 12	6.99	35.3		3/5/12 12:00 to 3/5/12 18:00	0.63
11 Apr 12	12.2	26.5		4/11/12 11:00 to 4/11/12 12:00	0.01
3 May 12	5.74	64.3		5/3/12 8:00 to 5/4/12 1:00	0.67
5 Jun 12	2.1	10.2		6/5/12 9:00 to 6/6/12 1:00	0.73

Land Development Characteristics at Naval Base Kitsap

Naval Base Kitsap – Bremerton Outfall 015

Bremerton Outfall 015 is located in the Naval Base Kitsap. A complete data survey is available for this outfall describing the surface coverage and area of each surface type. Outfall 015 is comprised of residential, commercial, industrial, and institutional land uses, with buildings, landscaping, and light to heavy laydown concrete and asphalt covered areas. The watershed area for this outfall is approximately 104 acres. This site has pervious areas accounting for 41% of the total watershed. An aerial photograph, along with different land use characteristics of the site, is shown in the following figures.



Drainage overview and Land use characterization for Bremerton Outfall 015


04/08/2013


04/08/2013


846
04/08/2013


DANGER
04/08/2013


04/09/2013


04/09/2013


04/09/2013


04/09/2013


04/09/2013


04/09/2013


04/09/2013


04/09/2013

Land Use Development Characteristics for Bremerton OF 015

LANDUSE	Residential	Commercial	Institutional	Navy Industrial	Total
Roofs	**(ac)**	**(ac)**	**(ac)**	**(ac)**	**(ac)**
1 Roofs Flat - directly connected to drains	0.43	3.09	0	3.29	6.81
2 Roofs Flat - drains to asphalt/concrete	0.71	1.22	0	0	1.93
3 Roofs Flat - drains to soils	0	0	0	0	0
4 Roofs Flat - drains to vegetation	0.05	0.02	0	0	0.07
5 Roofs Flat - drains to other surface (artificial turf, rock, gravel, etc.)	0	0	0	0	0
6 Roofs Pitched - directly connected	2.64	1.93	0	0	4.57
7 Roofs Pitched - drains to asphalt/concrete	0.40	0.03	0	1.80	2.23
8 Roofs Pitched - drains to soils	0	0	0	0	0
9 Roofs Pitched - drains to vegetation	0.69	0	0.10	0	0.79
10 Roofs Pitched - drains to other surface (artificial turf, rock, gravel, etc.)	0	0	0	0	0
Parking/Streets/Sidewalks/Driveways					
13 Paved asphalt parking/storage - smooth/intermediate texture - directly connected to drains	6.01	8.07	0	0.14	14.22
14 Paved asphalt parking/storage - rough/very course texture - directly connected to drains	0.34	1.13	0.79	3.48	5.73
15 Paved asphalt parking/storage - drains to pervious	0	0	0	0	0
16 Paved concrete parking/storage - smooth - directly connected	1.13	0	0	0	1.13
17 Paved concrete parking/storage - intermediate - directly connected	0	0	0	0	0
18 Paved concrete parking/storage - drains to pervious	0	0	0	0	0
19 Unpaved parking/storage - directly connected to drains	0	0	0	0	0
20 Unpaved parking/storage - drains to pervious	0	0	0	0	0
25 Driveways/loading dock -asphalt- directly connected	0.68	1.04	0	0.68	2.41

Land Use Development Characteristics for Bremerton OF 015 (continued)

26 Driveways/loading dock -concrete- directly connected	0.13	0.40	0	0.05	0.57
27 Driveways/loading dock - drains to pervious	0.20	0.17	0.05	0	0.42
31 Sidewalks - directly connected to drains	0.80	1.53	0	0.06	2.39
32 Sidewalks - drains to pervious	0.05	0	0	0	0.05
37 Streets- directly connected to drains	5.36	4.05	0.34	2.11	11.86
38 Streets-drains to pervious	0	0	0	0	0
Pervious Areas					
45 Landscaping areas - soils	0	0	0	0	0
46 Landscaping areas - vegetation	23.79	5.49	8.51	2.07	39.87
51 Landscaping areas around structures- soils	0	0	0	0	0
52 Landscaping areas around structures - vegetation	0	0	0	0	0
53 Landscaping areas around structures- other/infiltration area	0	0.42	0	0	0.42
57 Undeveloped areas - soils	0.81	1.03	0	0	1.84
58 Undeveloped areas - vegetation	0	0	0	0	0
71 Other pervious infiltration areas	0.07	0.16	0	0	0.23
Special Areas					
84 OIA1 - Airfield apron/runway paved areas - directly connected	0	0	0	0	0
OIA1 - Airfield apron/runway paved areas- drains to soil	0	0	0	0	0
OIA1 - Airfield apron/runway paved areas - drains to vegetation	0	0	0	0	0
85 OIA2 - Airfield other paved areas- directly connected	0	0	0	0	0
OIA2 - Airfield other paved areas- drains to soil	0	0	0	0	0
OIA2 - Airfield other paved areas- drains to vegetation	0	0	0	0	0
86 OIA3 - Light laydown concrete areas- directly connected to drains	0.02	0.20	0	0	0.21
OIA3 - Light laydown concrete areas - drains to soil	0	0	0	0	0
OIA3 - Light laydown concrete areas - drains to vegetation	0.22	0	0	0	0.22

Land Use Development Characteristics for Bremerton OF 015 (continued)

87 OIA4 - Moderate laydown concrete areas - directly connected	0.11	0.02	0	0	0.13
OIA4 - Moderate laydown concrete areas - drains to soil	0	0	0	0	0
OIA4 - Moderate laydown concrete areas - drains to vegetation	0.45	0	0	0	0.45
88 OIA5 - Heavy laydown concrete areas- directly connected	0	0.37	0	0.05	0.43
OIA5 - Heavy laydown concrete areas - drains to soil	0	0	0	0	0
OIA5 - Heavy laydown concrete areas- drains to vegetation	0	0	0	0	0
89 OIA6 - Light laydown asphalt areas - directly connected	0	0	0	0	0
OIA6 - Light laydown asphalt areas- drains to soil	0	0	0	0	0
OIA6 - Light laydown asphalt areas- drains to vegetation	0	0	0	0	0
90 OIA7 - Moderate laydown asphalt areas- directly connected	0	0.27	0	1.78	2.05
OIA7 - Moderate laydown asphalt areas- drains to soil	0	0	0	0	0
OIA7 - Moderate laydown asphalt areas- drains to vegetation	0	0	0	0	0
91 OIA8 - Heavy laydown asphalt areas - directly connected	0	0	0	1.16	1.16
OIA8 - Heavy laydown asphalt areas - drains to soil	0	0	0	0	0
OIA8 - Heavy laydown asphalt areas - drains to vegetation	0	0	0	0	0
92 OIA9 - Galvanized metal roofs- directly connected	0	0	0	0	0
OIA9 - Galvanized metal roofs - drains to soil	0	0	0	0	0
OIA9 - Galvanized metal roofs- drains to vegetation	0	0	0	0	0
93 OIA10 - Other galvanized materials- directly connected to drains	0	0.15	0	0.21	0.36
OIA10 - Other galvanized materials - drains to soil	0	0.07	0	0	0.07
OIA10 - Other galvanized materials - drains to vegetation	0.47	0.23	0.25	0	0.95

Land Use Development Characteristics for Bremerton OF 015 (continued)

99 ONPIA11 - Light laydown unpaved - drains to soil	0	0	0	0	0
99 ONPA11 - Light laydown unpaved - drains to vegetation	0	0	0	0	0
100 ONPA12 - Moderate laydown unpaved - drains to soil	0	0	0	0	0
101 ONPA12 - Moderate laydown unpaved - drains to vegetation	0	0	0	0	0
102 ONPA13 - Heavy laydown unpaved - drains to soil	0	0	0	0	0
103 ONPA13 - Heavy laydown unpaved - drains to vegetation	0	0	0	0	0
Total Area (acres)	45.53	31.11	10.04	16.90	103.58

Stormwater Quality at Naval Base Kitsap

Stormwater Monitoring for Bremerton Outfall 015

Storm	Date	Sample Type	Rain fall (in)	Total Cu (µg/L)	Total Zn (µg/L)	Dissolved Cu (µg/L)	Dissolved Zn (µg/L)	Note:	Associated Rainfall Day/Event	Rain Depth Associated with Monitored Rain Event
SW04	3/1/2011	EMC	0.54	8.23	65	4.98	48.5		3/1/11 0:00 to 3/1/11 8:00	0.19
SW05	3/8/2011	EMC	0.08	10.7	76.4	5.22	50.4		3/8/11 11:00 to 3/8/11 16:00	0.32
SW07	4/14/2011	EMC	0.75	11.8	76.4	5.3	47.3		4/13/11 18:00 to 4/14/11 13:00	0.5
SW08	11/22/2011	EMC	1.82	8.05	56.8	3.94	39.7		11/21/11 12:00 to 11/23/11 14:00	6.61
SW09	1/21/2012	EMC	1.29	9.74	69.1	2.8	37.7		1/21/12 4:00 to 1/21/12 11:00	0.45
SW10	2/29/2012	EMC	0.58	8.71	74.8	4.91	57.2		2/28/12 23:00 to 2/29/12 21:00	0.86
SW11	3/15/2012	EMC	1.75	10.8	68	3.07	35.5		3/12/12 12:00 to 3/15/12 23:00	3.58
SW12	4/20/2012	EMC	0.46	14.4	78.4	6.89	48.7		4/19/12 21:00 to 4/20/12 18:00	0.69
SW12	4/20/2012	PSNS015-1	0.46	17.4	76.2	7.43	43.7	Timed Composite Sampling- First Flush	4/19/12 21:00 to 4/20/12 18:00	0.69

Stormwater Monitoring for Bremerton Outfall 015 (continued)

SW12	4/20/2012	PSNS015-2	0.46	12.3	62.6	6.02	34.2	Timed Composite Sampling	4/19/12 21:00 to 4/20/12 18:00	0.69
SW12	4/20/2012	PSNS015-3	0.46	9.88	57.1	5.77	37.5	Timed Composite Sampling	4/19/12 21:00 to 4/20/12 18:00	0.69
SW12	4/20/2012	PSNS015-4	0.46	11.2	70.6	7.18	52.5	Timed Composite Sampling	4/19/12 21:00 to 4/20/12 18:00	0.69
SW12	4/20/2012	PSNS015-5	0.46	14.8	84.8	7.38	54	Timed Composite Sampling	4/19/12 21:00 to 4/20/12 18:00	0.69
SW12	4/20/2012	PSNS015-6	0.46	12.6	76.1	7.08	51.8	Timed Composite Sampling	4/19/12 21:00 to 4/20/12 18:00	0.69
SW12	4/20/2012	PSNS015-7	0.46	9.47	64.4	7.13	55.6	Timed Composite Sampling	4/19/12 21:00 to 4/20/12 18:00	0.69
SW12	4/20/2012	PSNS015-8	0.46	10.1	92.8	7.22	79.2	Timed Composite Sampling	4/19/12 21:00 to 4/20/12 18:00	0.69
SW12	4/20/2012	PSNS015-9	0.46	9.67	82.1	7.32	72.2	Timed Composite Sampling	4/19/12 21:00 to 4/20/12 18:00	0.69
SW12	4/20/2012	PSNS015-10	0.46	8.95	92	4.49	71	Timed Composite Sampling	4/19/12 21:00 to 4/20/12 18:00	0.69
SW12	4/20/2012	PSNS015-11	0.46	3.49	70.5	1.68	65.1	Timed Composite Sampling	4/19/12 21:00 to 4/20/12 18:00	0.69
SW12	4/20/2012	PSNS015-12	0.46	2.87	32.8	1.41	30.3	Timed Composite Sampling	4/19/12 21:00 to 4/20/12 18:00	0.69
SW12	4/20/2012	PSNS015-13	0.46	7.73	83.3	5.45	79.4	Timed Composite Sampling	4/19/12 21:00 to 4/20/12 18:00	0.69
SW12	4/20/2012	PSNS015-14	0.46	10.7	69.9	8.06	61.7	Timed Composite Sampling	4/19/12 21:00 to 4/20/12 18:00	0.69

Stormwater Monitoring for Bremerton Outfall 015 (continued)

SW12	4/20/2012	PSNS015-15	0.46	8.95	98.5	6.71	87.6	Timed Composite Sampling	4/19/12 21:00 to 4/20/12 18:00	0.69
SW12	4/20/2012	PSNS015-16	0.46	28.5	108	2.96	22.1	Timed Composite Sampling	4/19/12 21:00 to 4/20/12 18:00	0.69
SW12	4/20/2012	PSNS015-17	0.46	8.69	80.7	6.07	65.7	Timed Composite Sampling	4/19/12 21:00 to 4/20/12 18:00	0.69
SW12	4/20/2012	PSNS015-18	0.46	10	80.7	7.51	68	Timed Composite Sampling	4/19/12 21:00 to 4/20/12 18:00	0.69
SW13	12/17/2012	EMC	1.49	5.94	33.0	2.34	21.1		12/16/12 17:00 to 12/17/12 12:00	2.01
SW15	2/22/2013	EMC	0.57	9.55	66.4	3.99	44.3		2/22/13 11:00 to 2/22/13 22:00	0.87
SW16	3/20/2013	EMC	1.49	12.6	73.3	4.53	39.8		3/19/13 22:00 to 3/20/13 20:00	1.7

Land Development Characteristics at Naval Station Everett

Naval Station Everett – Everett Outfall A

Everett Outfall A is located in the Naval Station Everett. A complete data survey is available for this outfall describing the surface coverage and area of each surface type. Outfall A is comprised of industrial land uses, with buildings, landscaping, and light to heavy laydown concrete and asphalt areas. The watershed area for this outfall is approximately 15 acres. This site has pervious areas accounting for 10% of the total watershed. An aerial photograph, along with different land use characteristics, is shown in the following figure.

Drainage overview and Land use characterization for Everett Outfall A

	
	
KEEP OUTRIGGERS OFF	MOUND #1 RWS-MA 480 VOLTS

Photos taken during site survey of Everett OF-A

Land Use Development Characteristics for Everett OF A

LANDUSE	**Everett OF A**
Roofs	**Area (ac)**
1 Roofs Flat - directly connected to drains	0.07
2 Roofs Flat - drains to asphalt/concrete	0.09
3 Roofs Flat - drains to soils	0
4 Roofs Flat - drains to vegetation	0
5 Roofs Flat - drains to other surface (artificial turf, rock, gravel, etc.)	0
6 Roofs Pitched - directly connected	0.02
7 Roofs Pitched - drains to asphalt/concrete	0.28
8 Roofs Pitched - drains to soils	0
9 Roofs Pitched - drains to vegetation	0
10 Roofs Pitched - drains to other surface (artificial turf, rock, gravel, etc.)	0
Parking/Streets/Sidewalks/Driveways	
13 Paved asphalt parking/storage - smooth/intermediate texture - directly connected to drains	0.06
14 Paved asphalt parking/storage - rough/very course texture - directly connected to drains	0

Land Use Development Characteristics for Everett OF A (continued)

15 Paved asphalt parking/storage - drains to pervious	0
16 Paved concrete parking/storage - smooth - directly connected	2.04
17 Paved concrete parking/storage - intermediate - directly connected	0
18 Paved concrete parking/storage - drains to pervious	0
19 Unpaved parking/storage - directly connected to drains	0
20 Unpaved parking/storage - drains to pervious	0
25 Driveways/loading dock -asphalt- directly connected	0
26 Driveways/loading dock -concrete- directly connected	0
27 Driveways/loading dock - drains to pervious	0
31 Sidewalks - directly connected to drains	0.73
32 Sidewalks - drains to pervious	0
37 Streets- directly connected to drains	2.56
38 Streets-drains to pervious	0
Pervious Areas	
45 Landscaping areas - soils	0
46 Landscaping areas - vegetation	1.45
51 Landscaping areas around structures- soils	0
52 Landscaping areas around structures - vegetation	0
53 Landscaping areas around structures- other/infiltration area	0
57 Undeveloped areas - soils	0
58 Undeveloped areas - vegetation	0
71 Other pervious infiltration areas	0.08
Special Areas	
84 OIA1 - Airfield apron/runway paved areas - directly connected	0
OIA1 - Airfield apron/runway paved areas- drains to soil	0
OIA1 - Airfield apron/runway paved areas - drains to vegetation	0
85 OIA2 - Airfield other paved areas- directly connected	0
OIA2 - Airfield other paved areas- drains to soil	0
OIA2 - Airfield other paved areas- drains to vegetation	0

Land Use Development Characteristics for Everett OF A (continued)

86 OIA3 - Light laydown concrete areas- directly connected to drains	6.81
OIA3 - Light laydown concrete areas - drains to soil	0
OIA3 - Light laydown concrete areas - drains to vegetation	0
87 OIA4 - Moderate laydown concrete areas - directly connected	0
OIA4 - Moderate laydown concrete areas - drains to soil	0
OIA4 - Moderate laydown concrete areas - drains to vegetation	0
88 OIA5 - Heavy laydown concrete areas- directly connected	0
OIA5 - Heavy laydown concrete areas - drains to soil	0
OIA5 - Heavy laydown concrete areas- drains to vegetation	0
89 OIA6 - Light laydown asphalt areas - directly connected	0
OIA6 - Light laydown asphalt areas- drains to soil	0
OIA6 - Light laydown asphalt areas- drains to vegetation	0
90 OIA7 - Moderate laydown asphalt areas- directly connected	0.21
OIA7 - Moderate laydown asphalt areas- drains to soil	0
OIA7 - Moderate laydown asphalt areas- drains to vegetation	0
91 OIA8 - Heavy laydown asphalt areas - directly connected	0.193
OIA8 - Heavy laydown asphalt areas - drains to soil	0
OIA8 - Heavy laydown asphalt areas - drains to vegetation	0
92 OIA9 - Galvanized metal roofs- directly connected	0
OIA9 - Galvanized metal roofs - drains to soil	0
OIA9 - Galvanized metal roofs- drains to vegetation	0
93 OIA10 - Other galvanized materials- directly connected to drains	0.92
OIA10 - Other galvanized materials - drains to soil	0
OIA10 - Other galvanized materials - drains to vegetation	0

Land Use Development Characteristics for Everett OF A (continued)

99 ONPIA11 - Light laydown unpaved - drains to soil	0
99 ONPA11 - Light laydown unpaved - drains to vegetation	0
100 ONPA12 - Moderate laydown unpaved - drains to soil	0
101 ONPA12 - Moderate laydown unpaved - drains to vegetation	0
102 ONPA13 - Heavy laydown unpaved - drains to soil	0
103 ONPA13 - Heavy laydown unpaved - drains to vegetation	0
Total Area (acres)	15.48

Stormwater Quality at Naval Station Everett

Stormwater Monitoring for Everett Outfall A (Rain information based on Everett Rain Gage)

Date	Iron (µg/L)	Lead (µg/L)	Cu (µg/L)	Zn (µg/L)	Aluminum (µg/L)	Associated Rainfall Day/ Event	Event Rain Depth (in)
11/5/2009	700	ND	15	ND	1400	11/5/09 11:00 to 11/5/09 23:00	0.4
8/26/2010	1950	49	47	190	1180	8/26/10 11:00 to 8/27/10 6:00	0.7
9/23/2010			8	38		9/23/10 10:00 to 9/23/10 11:00	0.1
12/20/2010			19	95		12/19/10 9:00 to 12/19/10 10:00	0.1
1/20/2011			29	80		1/20/2011 12:00 to 1/21/2011 13:00	1.5
5/2/2011	780	16	21	100	540	5/2/11 9:00 to 5/2/11 10:00	0.1
9/26/2011	600	14	70	90	300	9/25/11 12:00 to 9/25/11 13:00	0.1
12/30/2011	2230	32	48	299	1060	12/29/11 23:00 to 12/30/11 0:00	0.1
4/3/2012			227	45		4/3/12 16:00 to 4/3/12 22:00	0.28*

Stormwater Monitoring for Everett Outfall A (Rain information based on Everett Rain Gage) (continued)

7/13/2012	560	9.5	39	99	360	7/13/12 16:00 to 7/13/12 17:00	0.02*
11/28/2012	580	0.7	236	42	350	11/28/12 21:00 to 11/29/12 6:00	0.22*
1/23/2013	1740	19	64	220	1030	1/23/13 18:00 to 1/24/13 7:00	0.27*
4/4/2013	1080	18	126	381	610	4/4/13 17:00 to 4/5/13 10:00	0.38*

*Snohomish County Airport Rain gage data as the Everett data ended in 2011. The earlier data were obtained from the Everett rain gage location.

WinSLAMM Calibration Results

WinSLAMM was calibrated using the above listed site data collected at the various naval facilities located in California, Virginia, and Washington. The California and Washington naval industrial calibration files developed during the prior project year were not modified (except to comply with several model enhancements that we made since those earlier calibrations, such as the compacted soil factors and routing of particle size distributions). During the current project period, additional data were available for "dry side" naval facilities in the San Diego area (mostly residential and commercial/institutional areas), some additional land uses in the Puget Sound area (again mostly residential and commercial/institutional areas), and for naval industrial areas in the Little Creek, Virginia areas. These sites are all described in earlier sections of this report. The calibration efforts for the current project period therefore extended WinSLAMM to these other land uses found on naval facilities, and for a new area (Virginia). In addition, the prior California and Washington calibrations were also verified using these new data from the additional monitoring locations.

The calibration process started with the San Diego "dry side" locations and data, and the files were then used with the prior industrial area data for the "wet side" locations having mostly industrial land uses. After this calibration effort (described below), the Virginia locations were calibrated (all naval industrial land uses) based on the regional WinSLAMM land use calibration data (based on the National Stormwater Quality Database), but adjusted using the locally naval base collected information and data. The Puget Sound calibration effort started with mixed land use areas for the residential and commercial/institutional land uses, and then used the prior industrial area calibration files from the prior project phase with the other locations.

The first calibration activities focused on the TSS data at each location and land use. Calibration started with using the regional calibration files for the southwest for all land uses besides the industrial areas (which used the prior navy calibrated files). Model runs were conducted using truncated rain files that had the best rain data available corresponding to the events monitored at the site. The TSS concentrations and mass loadings were examined for patterns and other relationships to indicate where adjustments were needed. As an example, if the loads for the small events were low, the directly connected impervious areas (locations that generated flows during the small events) were adjusted to closely match the observed loads. Then the complete rain series available was examined and adjustments were then made to the non-paved areas to closely match the observed loads. When multiple sites of the same land use occurred at one area, all of the land use areas were examined and adjusted together to obtain the least sum of squares of the residuals. Basically, the sum of all the event loads for all sites were compared and the ratio of the observed to the calculated load sum was then used as a factor to modify the calibration file data (again, the industrial data was not changed from the prior calibrations).

Besides the particle concentration file data, changes were also simultaneously made to the street TSS washoff delivery file (as the street runoff TSS load is calculated by the model and does not use a calibration file directly). Therefore, matching the sum of loads for the observed and calculated data sets was the primary calibration objective. When a satisfactory overall match was obtained, further analyses were conducted examining individual event loads and concentration values. Further adjustments were made in an attempt to best represent the overall range and variation in loads and concentrations.

After the TSS calibrations were completed, copper and zinc calibrations were next conducted for both particulate and filtered conditions, starting with mass discharges and then concentrations. After these calibrations were made for the residential, commercial, and institutional land uses, the prior industrial calibration files were used for newer industrial areas for the California and Washington sites. The Virginia industrial calibrations only reflected the current data as prior naval facility data were not available for that area.

As shown in the following plots and tables, the performances of the calibrations were quite satisfactory for the load calculations, but were not as good for the concentration data. While the average concentrations matched well, the calculated concentration values for individual events sometimes were less variable than observed. This is mostly associated with various uncertainties of the monitored data, such as the periodic monitored events over long periods of time resulting in artificially long interevent periods (partially compensated by using special street delivery factors), varying amounts of observations from the different sites for the different constituents, and unknown site activities in the past that do not correspond to currently observed site conditions. Overall, these calibrated model files were then used to calculate the expected sources of the flows, particulates, copper, and zinc from the different study areas, as shown in the following report section.

Observed and Calculated TSS Loads and Average Concentrations

			TSS sum of loads, total (lbs)		TSS conc., average (mg/L)	
San Diego		Number of monitored events	observed	calculated	observed	calculated
OF51	High density residential and big box commercial	3	292	187	164	116
OF70	High density residential and big box commercial	6	1386	1838	100	103
OF72	High density residential (small portion) and big box commercial (mostly)	14	2341	2312	127	73
OF73	Big box commercial (mostly parking)	9	803	420	210	59
Sierra Pier	Industrial pier	37	2,085	3,460	249	238
All San Diego resid/commer sites combined		32	4,822	4,759	149	78
Virginia, St. Juliennes OF 40&41	scrapyard	7	384	458	19	21
Washington, Bangor OF 02	Large industrial area with swales	4	808	670	5	61 (w/o swale effects)

Observed and Calculated Total Copper Loads and Average Concentrations

			Total copper, sum of total loads (lbs)		Total copper conc., average (µg/L)	
San Diego		Number of monitored events	observed	calculated	observed	calculated
OF51	High density residential and big box commercial	3	0.17	0.12	116	66
OF70	High density residential and big box commercial	6	0.37	0.76	49	75
OF72	High density residential (small portion) and big box commercial (mostly)	10	1.65	1.55	82	90
OF73	Big box commercial (mostly parking)	4	0.13	0.05	143	80
Sierra Pier	Industrial pier	35	7.9*	1.7	776*	110
All San Diego resid/commer sites combined		23	2.33	2.48	90	81
Virginia, St. Juliennes OF 40&41	scrapyard	7	0.62	0.60	24	30
Washington, Bremerton OF15	Large mixed land use area	11	1.02	1.03	10	9.8
Washington, Bangor OF 02	Large industrial area with swales	14	0.079	0.17	8.2	14
Washington, Everett, OFA	Industrial piers	13	0.37*	0.08	142*	37

* several very high concentrations observed

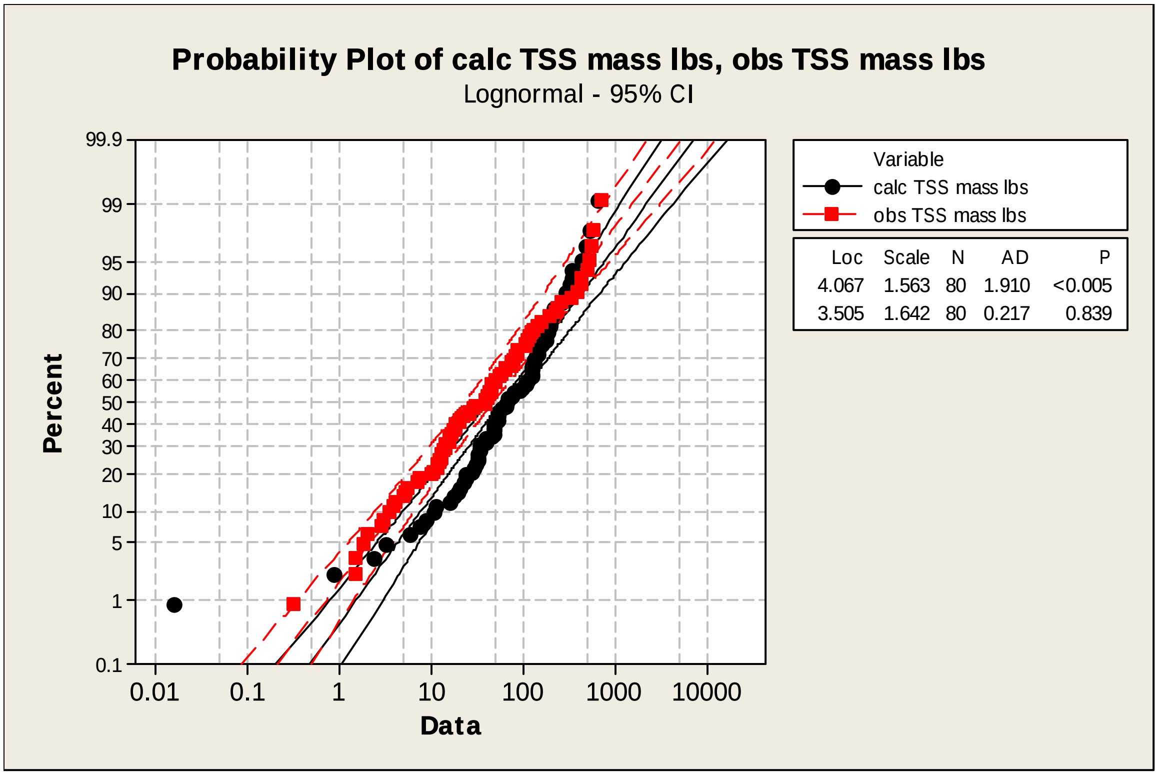
Observed and Calculated Total Zinc Loads and Average Concentrations

			Total zinc, sum of total loads (lbs)		Total zinc conc., average (µg/L)	
San Diego		Number of monitored events	observed	calculated	observed	calculated
OF51	High density residential and big box commercial	3	0.93	0.68	257	384
OF70	High density residential and big box commercial	6	3.3	8.1	207	426
OF72	High density residential (small portion) and big box commercial (mostly)	4	4.7	5.3	1,074*	581
OF73	Big box commercial (mostly parking)	4	4.1*	1.7	1,679*	530
All San Diego resid/commer sites combined		17	13.0	15.7	766	480
Virginia, St. Juliennes OF 40&41	scrapyard	7	1.9	3.1	91**	158
Washington, Bremerton OF15	Large mixed land use area	11	6.3	6.3	61	60
Washington, Bangor OF 02	Large industrial area with swales	14	0.42	0.49	44	46
Washington, Everett, OFA	Industrial piers	13	0.23	0.26	102	122

* several very high concentrations observed

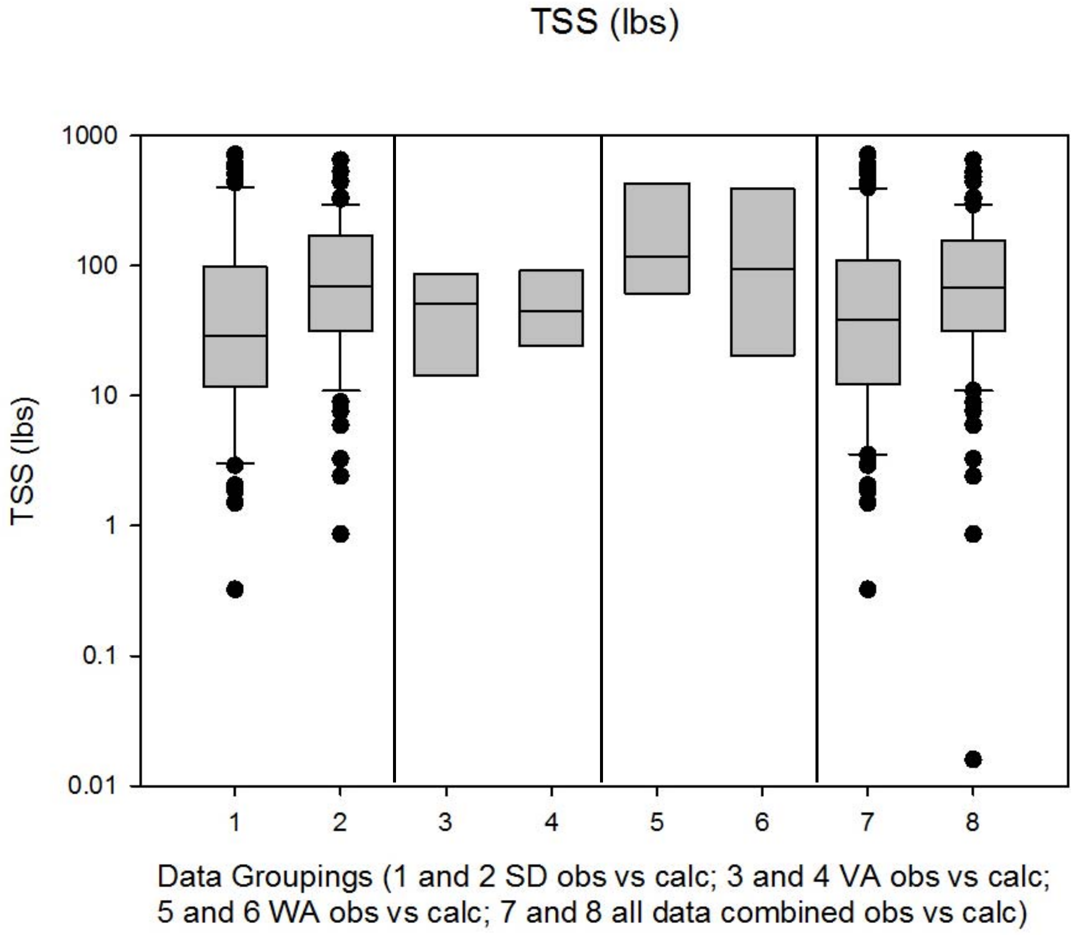
** filterable concentrations greater than total concentrations when both sites examined

The following are plots and calculations describing the performance for the TSS mass calibrations as an example. The additional data for the TSS concentrations and the copper and zinc calibrations are shown in Appendix C. The Mann-Whitney rank sum tests compared the medians of the observed and calculated data sets, while the calibrations focused on the sum of loads and the average concentrations. Therefore, a number of these test results indicate significant differences in the observed vs. calculated median values, while it is likely the average and load data sets are not significantly different. The calibration test results cannot be presented with a single performance value, nor were the calibrations done only examining single relationships. The overall patterns were also considered in addition to the primary sum of loads values. As noted previously, the inconsistent data collection efforts, relatively few data, and lack of historical site activities likely added to less desirable calibration results for some conditions. However, most of these results are very good and the calibrated model was used to calculate the expected sources of the flows and pollutants in the following section.



Loc	Scale	N	AD	P
4.067	1.563	80	1.910	<0.005
3.505	1.642	80	0.217	0.839

The above figure shows probability plots for the observed and calculated TSS masses for all sites combined, showing similar and overlapping distributions. The 95% confidence intervals (CI) for each set of data are also shown. Generally, these two data sets overlap (they cross at both the top and bottom of the range and the CI bands are close). These are log-normal probability plots and also indicate how closely the data distributions reflect normal conditions (after being log-transformed). If the plot is a straight line, they are likely normally distributed. This plot was prepared with Minitab (version 16) and also includes Anderson-Darling (AD) test statistic values in the data summary box. If the AD p value is small (<0.05), then the data set is statistically different from a normal distribution; if large (>0.05) then there is insufficient data to indicate a statistically significant difference. In the above example, the observed TSS mass values (shown as red squares) form a reasonably straight line except for a few extreme values, and the AD test statistic has a p value of 0.84. In contrast, the calculated TSS mass values (shown as black filled dots) have a greater curvature and an AD test statistic p value of <0.005 indicating they do not likely form a normal distribution. The main use of these probability plots is to illustrate the visual similarity of the observed and calculated distributions; data normality is not a goal as non-parametric statistical tests were used when examining the data. These data sets are not perfectly super-imposed and indicate some bias, especially some over-predictions in calculated TSS mass for some observed values.



The above box and whisker plot compares pairs of observed and calculated TSS mass loads for the San Diego (CA), Norfolk (VA), and Puget Sound (WA) study areas data, while the last pair includes the data from all of the sites combined. The box shows the median as the internal horizontal line in the boxes while the upper and lower ends of the boxes indicate the 75th and 25th percentile values respectively. The ends of the whiskers indicate the 5 and 95% percentile values, while the individual dots indicate observations outside of the 5th to 95th percentile range. Therefore, two adjacent plots indicate how the observed and calculated values compare. Generally, if the median of one box is above or below the 25th or 75th percentile ends of the adjacent box, the data sets are likely significantly different for moderately sized data sets. For this plot, the San Diego data sets may be different, while the other data pairs (and the overall data set) indicate better overlapping conditions. The following Mann-Whitney test statistics was used to calculate the probability of these differences (based on the data set medians and the overall variations).

Mann-Whitney Rank Sum Test for San Diego TSS Mass Data (based on medians)

Group	N	Missing	Median	25%	75%
SD obs TSS lbs	69	0	29	124	987
SD calc TSS lbs	69	0	69	31	168
Mann-Whitney U Statistic= 1696					
T = 4111.000 n(small)= 69 n(big)= 69 (P = 0.004)					

The difference in the median values between the two groups is greater than would be expected by chance; there is a statistically significant difference (P = 0.004), as indicated on the above box and whisker plot

Mann-Whitney Rank Sum Test for Virginia TSS Mass Data (based on medians)

Group	N	Missing	Median	25%	75%
VA obs TSS lbs	7	0	51	14	87
VA calc TSS lbs	7	0	44	24	91
Mann-Whitney U Statistic= 21					
T = 49.000 n(small)= 7 n(big)= 7 P(est.)= 0.701 P(exact)= 0.710					

The difference in the median values between the two groups is not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.71)

Mann-Whitney Rank Sum Test for Washington TSS Mass Data (based on medians)

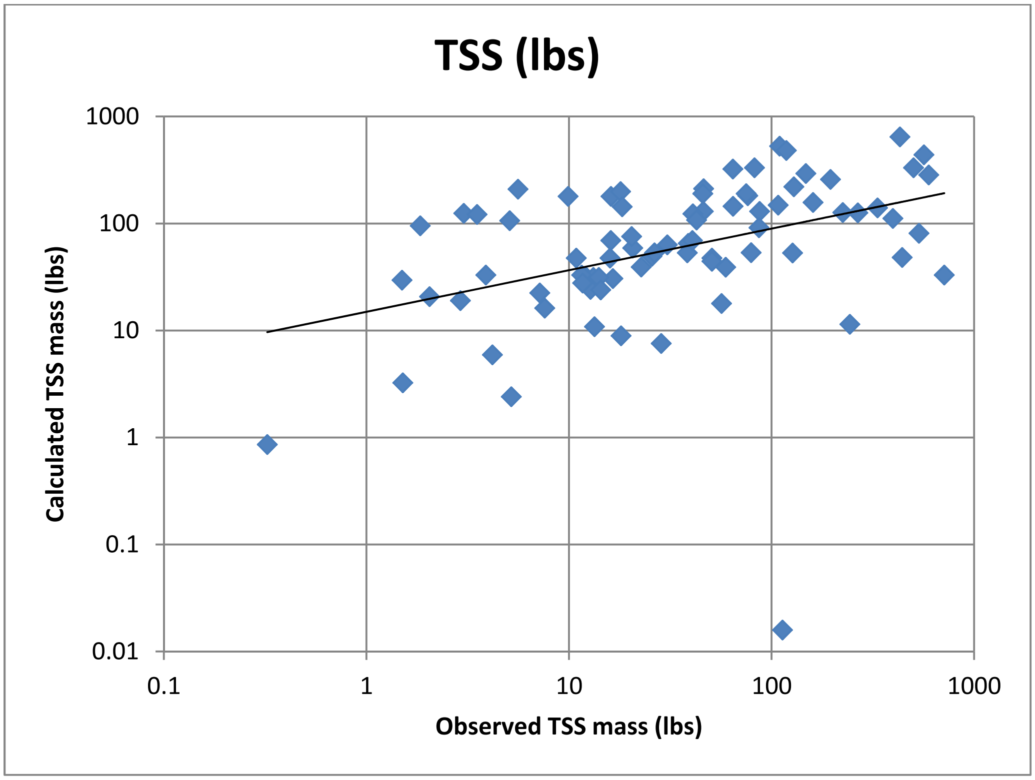
Group	N	Missing	Median	25%	75%
WA obs TSS lbs	4	0	116	60	430
WA calc TSS lbs	4	0	94	20	388
Mann-Whitney U Statistic= 5.000					
T = 21.000 n(small)= 4 n(big)= 4 P(est.)= 0.470 P(exact)= 0.486					

The difference in the median values between the two groups is not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.49)

t-Test: Paired Two Sample for Means for All TSS Mass Data Combined

	All observed TSS lbs	All calculated TSS lbs
Mean	101	117
Variance	25,072	16,219
Observations	80	80
Pearson Correlation	0.397	
Hypothesized Mean Difference	0	
df	79	
t Stat	-0.88	
P(T<=t) one-tail	0.19	

The number of observations (80 pairs) do not indicate a statistically significant difference between the two data sets (P = 0.40)



The above scatterplot compares the observed and calculated TSS mass loads for individual events. The preferred plot would be a 45 degree line with little scatter (as better indicated for copper and zinc loads as shown in Appendix C, for example). For the TSS mass loads shown on this plot, the events with small mass loadings have over-predicted calculated loadings, as indicated in the probability plots shown previously.

Calculated Sources of Flows, Particulate Solids, Copper, and Zinc at Naval Facilities

The calibrated version of WinSLAMM was used to calculate the relative sources of the runoff volume, TSS, copper, and zinc at the naval bases examined during the 2013 site investigation and monitoring activities. The following sections describe the results of these calculations, focusing on three ranges of rains: small rains up to 0.5 inches in depth (normally associated with the largest number of runoff events), 0.5 to 1.5 inches in depth (normally associated with the majority of pollutant mass discharges), and >1.5 inches in depth (rarer rains associated with habitat destruction/bank instability and drainage issues).

San Diego Naval Facility Flow and Pollutant Sources

The following table summarizes the main source areas used in the source calculations, along with their descriptions. The analyses were separated into three land use categories: residential, commercial/institutional, and industrial areas. These three land use categories along with the source areas shown in this table were the basis for the simplified spreadsheet Navy stormwater model being developed for preliminary base calculations.

Source Area Categories for San Diego Source Contribution Analyses

Source Area Label	Description for Navy analyses	WinSLAMM source #	San Diego Sierra Pier (Naval indus)	San Diego OF51 (Resid)	San Diego OF51 (commer/ instit)	San Diego OF70 (resid)	San Diego OF70 (commer/ instit)	San Diego OF72 (resid)	San Diego OF72 (commer/ instit)	San Diego OF73 (resid)	San Diego OF73 (commer/ instit)
Roofs 1	Roofs Flat - connected	1	0.55	0.81		0.51	3.81	0.71	3.26		1.58
Roofs 3	Roofs Flat - disconnected	3				1.12	0.18		2.47		1.75
Roofs 6	Roofs Pitched - connected	6	0.29			0.23	1.3	2.77	1.29	0.02	
Roofs 9	Roofs Pitched - disconnected	9		0.15		1.81	1.36		0.26		
Paved parking 1	Paved parking-connected	13	0.22	4.73		16.12	4.15	5.71	10.9		4.42
Paved parking 3	Paved parking-disconnected	15		0.79		4.91	2.27	0.06	0.67		1.12
Unpaved parking 2	Unpaved parking-disconnected	20					0.78				
Driveways 1	Driveways/loading dock - connected	25	0.63			0.19		0.3			
Driveways 3	Driveways/loading dock - disconnected	27		0.35		0.59	0.52		0.21		
Sidewalks 1	Sidewalks - connected	31		0.46		0.73	0.32	0.88	0.66		1.25
Sidewalks 2	Sidewalks - disconnected	32		0.66							0.01
Streets 1	Streets - with curb and gutters	37				5.79	4.91	2.89	3.55	0.06	2.18
Large Landscaped areas 1	Landscaping areas /undeveloped areas (silty soils)	45		4.51	6.18	12.97	8.88	1.45	2.37		2.42
Small landscaped areas 1	Landscape/undeveloped areas next to buildings and/or parking lots (compacted silty soils)	51				0.3			0.17		0.45
Other pervious areas 1	Other pervious infiltration areas (sandy soils)	71				0.35	4.02	0.39	1.98		
Other impervious areas 3*	Light laydown paved areas-connected	86	0.74			0.03	0.17				1.21
Other impervious areas 3*	Light laydown paved areas-disconnected	86							0.28		
Other impervious areas 4	Moderate laydown paved areas - connected	87	1.08	0.06			0.04		0.02		0.33
Other impervious areas 5	Heavy laydown paved areas-connected	88						0.05	0.07		
Other non-paved areas 1	Light laydown unpaved - connected	99						0.05			

Source Area Categories for San Diego Source Contribution Analyses (continued)

Other non-paved areas 1	Light laydown unpaved - disconnected	99						0.01			
Other non-paved areas 5	Heavy laydown unpaved - disconnected	103						0.15			
Other impervious areas 10	Other galvanized materials paved- connected	93	0.91					0.01	0.55		0.14
Other impervious areas 10	Other galvanized materials paved- disconnected	93		0.48				0.08	0.01		0.06
	Total Area (acres)		4.42	13	6.18	45.65	32.71	15.51	28.84	0.08	16.92

* for areas having the same source area designation, use the most common condition, or create another land use for the duplicates

The following tables summarize the major source area contributions for these three rain categories for each outfall drainage area. Only those areas contributing at least 10% of the flows or pollutants are summarized on these tables. As expected, the directly connected impervious areas contribute most of the flows, but landscaped areas become important for the largest rains for some of the areas. Also, each source area usually has limited flow or pollutant contributions, requiring stormwater controls at several source areas or affecting the total area flows, to result in significant reductions.

Major flow sources for San Diego Naval Facilities:

Sub area and portion of total flow	0 to 0.5 inches	0.5 to 1.5 inches	>1.5 inches
NBSD OF51	Paved parking/storage 1 (56 to 60%) Paved parking/storage 3 (8.5 to 10%)	Paved parking/storage 1 (54 to 56%)	Paved parking/storage 1 (46 to 54%) Large landscaped area 2, other (4 to 12%)
NBSD OF70	Paved parking/storage 1 (32 to 39%) Paved parking/storage 3 (8 to 12%) Paved parking/storage 1, comer. (8 to 10%)	Paved parking/storage 1 (31 to 32%) Street 1 (10 to 11%)	Paved parking/storage 1 (29 to 31%) Street 1 (10 to 11%)
NBSD OF72	Paved parking/storage 1 (31 to 47%) Roofs 1 (10 to 16%) Roofs 3 (6 to 10%) Paved parking/storage 1, resid. (3 to 12%)	Paved parking/storage 1 (30%) Paved parking/storage 1, resid. (12 to 14%)	Paved parking/storage 1 (28 to 30%) Paved parking/storage 1, resid. (14%)
NBSD OF73	Paved parking/storage 1 (32 to 38%) Roofs 3 (11 to 14%) Roofs 1 (11 to 12%) Street 1 (0 to 14%)	Paved parking/storage 1 (31 to 32%) Roofs 1 (11%) Street 1 (14%) Roofs 3 (10 to 11%)	Paved parking/storage 1 (31 to 32%) Roofs 1 (11%) Street 1 (15%) Roofs 3 (10%)
Sierra Pier	Roofs 1 (16 to 41%) Roofs 6 (9 to 22%) Other impervious areas 4 (8 to 21%) Other impervious areas 10 (7 to 18%) Paved parking/storage 1 (6 to 17%) Other impervious areas 3 (6 to 15%) Driveways 1 (0 to 15%)	Other impervious areas 4 (21 to 23%) Other impervious areas 10 (18 to 20%) Other impervious areas 3 (15 to 16%) Driveways 1 (15%) Roofs 1 (14 to 16%)	Other impervious areas 4 (23 to 24%) Other impervious areas 10 (20%) Other impervious areas 3 (16%) Driveways 1 (15%) Roofs 1 (12 to 14%)

Major particulate solids sources for San Diego Naval Facilities:

Sub area and portion of total flow	0 to 0.5 inches	0.5 to 1.5 inches	>1.5 inches
NBSD OF51	Paved parking/storage 1 (71 to 81%) Paved parking/storage 3 (10 to 13%)	Paved parking/storage 1 (55 to 71%)	Paved parking/storage 1 (28 to 53%) Large landscaped area 2, other (5 to 21%) Large landscaped area 1 (4 to 15%)
NBSD OF70	Paved parking/storage 1 (51 to 59%) Paved parking/storage 3 (13 to 18%)	Paved parking/storage 1 (36 to 51%) Paved parking/storage 3 (9 to 13%) Street 1 (6 to 17%)	Paved parking/storage 1 (21 to 36%) Street 1 (14 to 19%)
NBSD OF72	Paved parking/storage 1 (42 to 74%) Paved parking/storage 1, resid. (8 to 22%) Roofs 6, resid. (2 to 12%) Roofs 3 (6 to 10%)	Paved parking/storage 1 (32 to 42%) Paved parking/storage 1, resid. (16 to 22%) Roofs 6, resid. (8 to 10%) Street1, resid. (6 to 14%)	Paved parking/storage 1 (29 to 32%) Street1, resid. (12 to 19%) Paved parking/storage 1, resid. (9 to 16%)
NBSD OF73	Paved parking/storage 1 (54 to 67%) Paved parking/storage 3 (11 to 15%) Other impervious area 3 (7 to 14%)	Paved parking/storage 1 (35 to 54%) Other impervious area 3 (14 to 22%) Paved parking/storage 3 (7 to 11%)	Paved parking/storage 1 (28 to 35%) Other impervious area 3 (22 to 27%)
Sierra Pier	Other impervious areas 4 (19 to 35%) Paved parking/storage 1 (9 to 19%) Roofs 1 (7 to 34%) Other impervious areas 3 (6 to 18%) Other impervious areas 10 (4 to 12%) Driveways 1 (0 to 17%)	Other impervious areas 4 (35 to 44%) Other impervious areas 3 (18 to 24%) Other impervious areas 10 (12 to 16%) Paved parking/storage 1 (9 to 10%) Driveways 1 (4 to 17%)	Other impervious areas 4 (34 to 44%) Other impervious areas 3 (24 to 31%) Other impervious areas 10 (16 to 20%) Paved parking/storage 1 (9 to 10%)

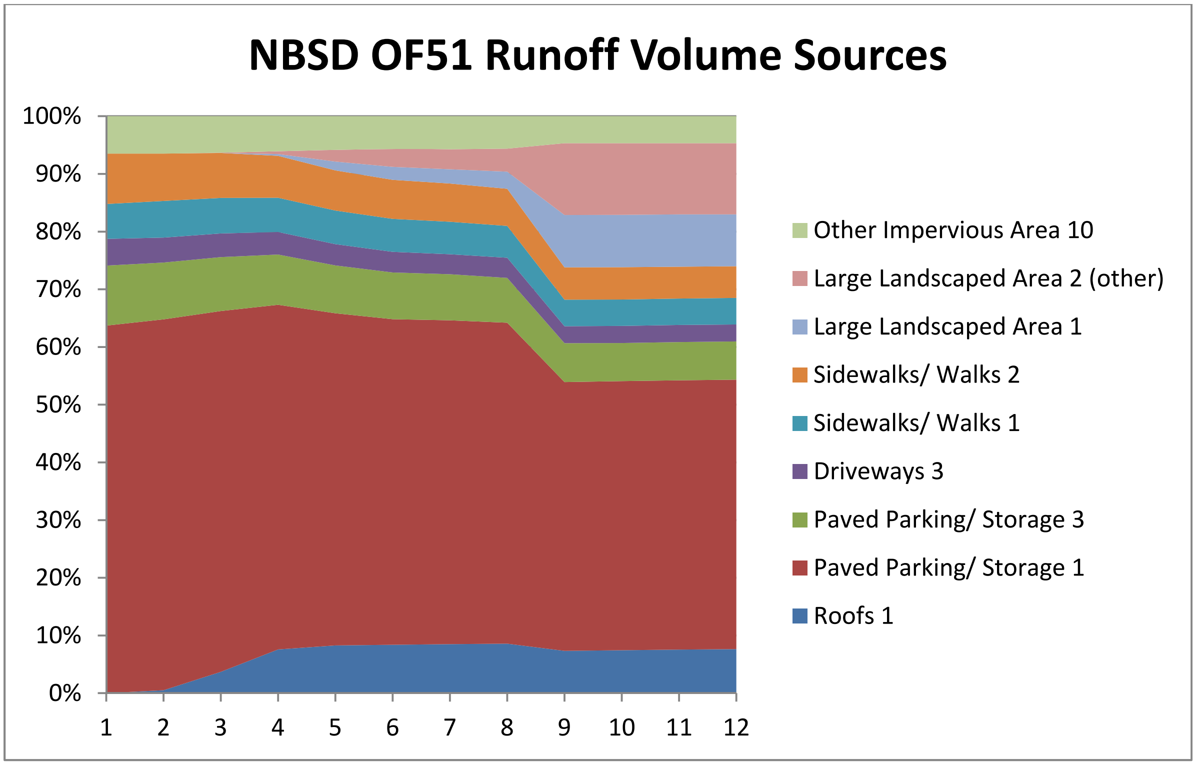
Major total copper sources for San Diego Naval Facilities:

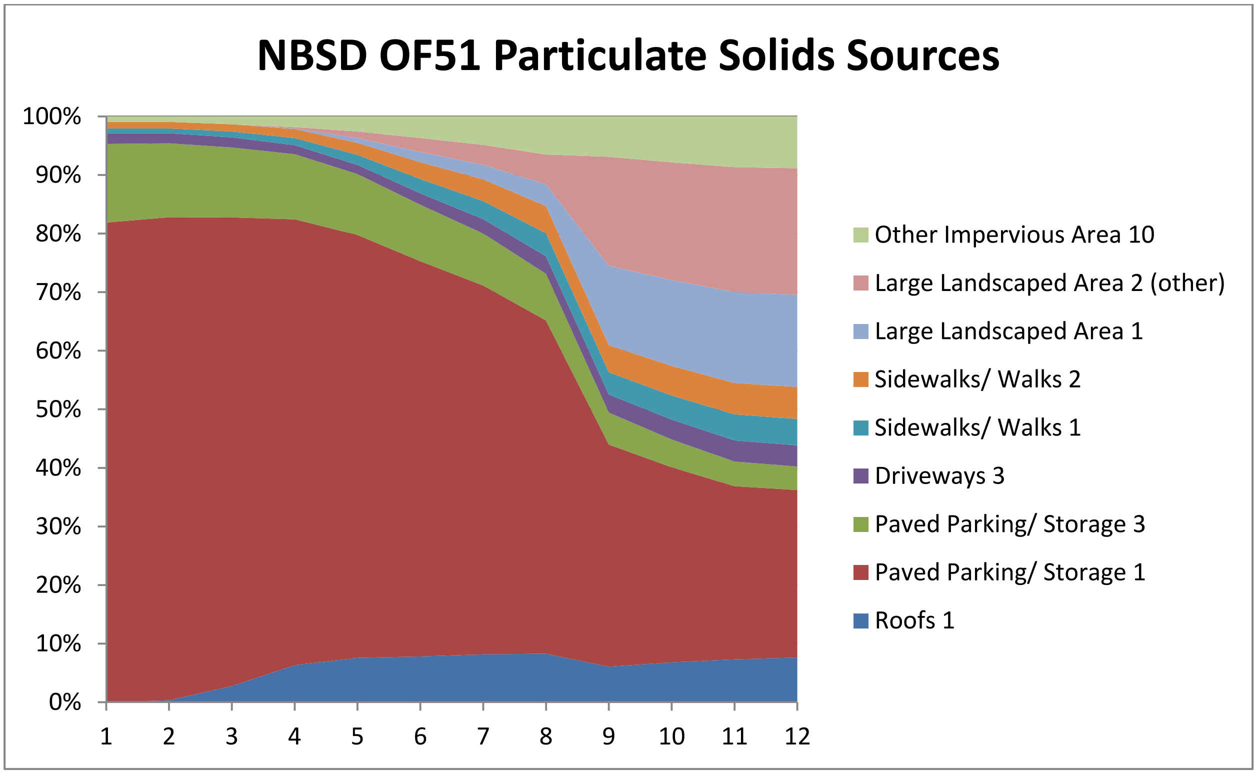
Sub area and portion of total flow	0 to 0.5 inches	0.5 to 1.5 inches	>1.5 inches
NBSD OF51	Paved parking/storage 1 (69 to 78%) Paved parking/storage 3 (10 to 13%)	Paved parking/storage 1 (61 to 69%)	Paved parking/storage 1 (48 to 61%)
NBSD OF70	Paved parking/storage 1 (71 to 81%) Paved parking/storage 3 (10 to 13%)	Paved parking/storage 1 (55 to 71%)	Paved parking/storage 1 (28 to 53%) Large landscaped area 2, other (5 to 21%) Large landscaped area 1 (4 to 15%)
NBSD OF72	Paved parking/storage 1 (50 to 65%) Roofs 1 (8 to 12%)	Paved parking/storage 1 (45 to 47%) Street 1 (10 to 12%)	Paved parking/storage 1 (43 to 45%) Street 1 (12 to 13%)
NBSD OF73	Paved parking/storage 1 (47 to 56%) Paved parking/storage 3 (10 to 13%) Sidewalks 1 (10%) Street 1 (0 to 14%)	Paved parking/storage 1 (42 to 47%) Sidewalks 1 (10 to 11%) Street 1 (13 to 17%)	Paved parking/storage 1 (41 to 42%) Street 1 (16 to 18%) Sidewalks 1 (11%)
Sierra Pier	Other impervious areas 4 (43 to 60%) Paved parking/storage 1 (8 to 27%) Other impervious areas 3 (8 to 14%) Other impervious areas 10 (7 to 13%) Roofs 1 (2 to 10%)	Other impervious areas 4 (58 to 60%) Other impervious areas 3 (14 to 15%) Other impervious areas 10 (13 to 14%)	Other impervious areas 4 (55 to 60%) Other impervious areas 3 (15 to 18%) Other impervious areas 10 (14 to 16%)

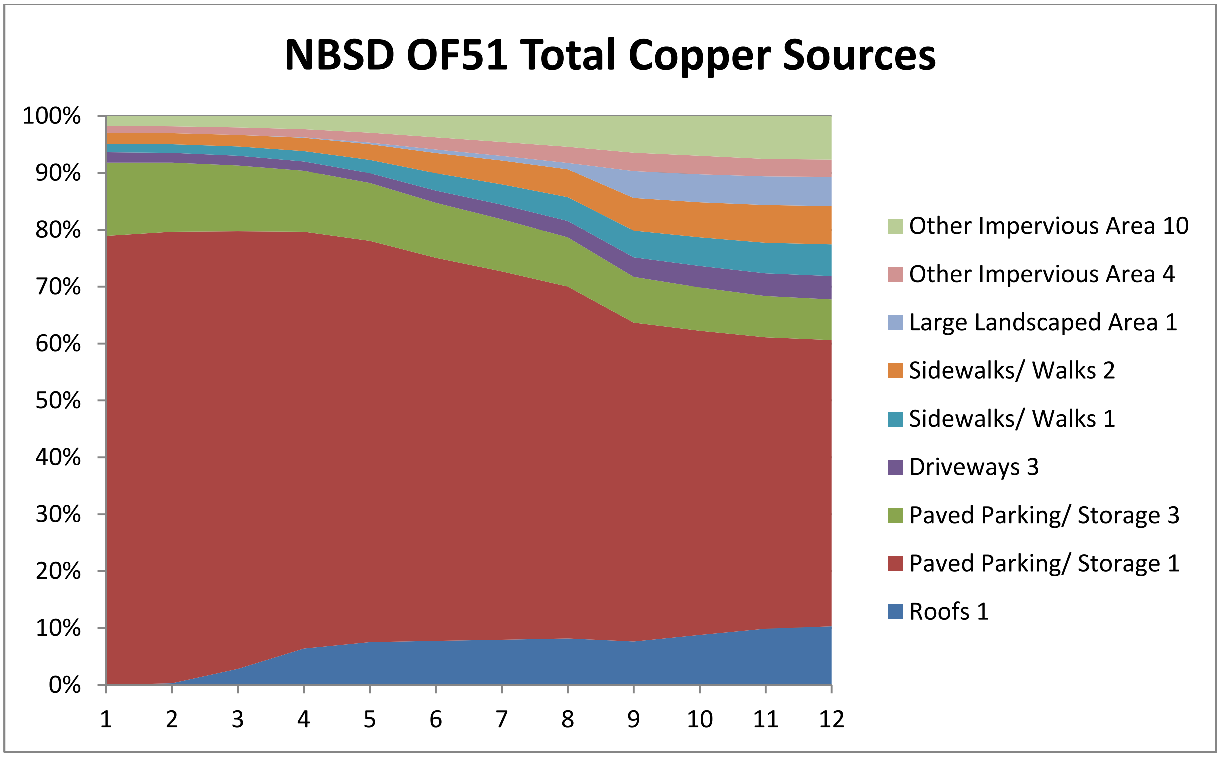
Major total zinc sources for San Diego Naval Facilities:

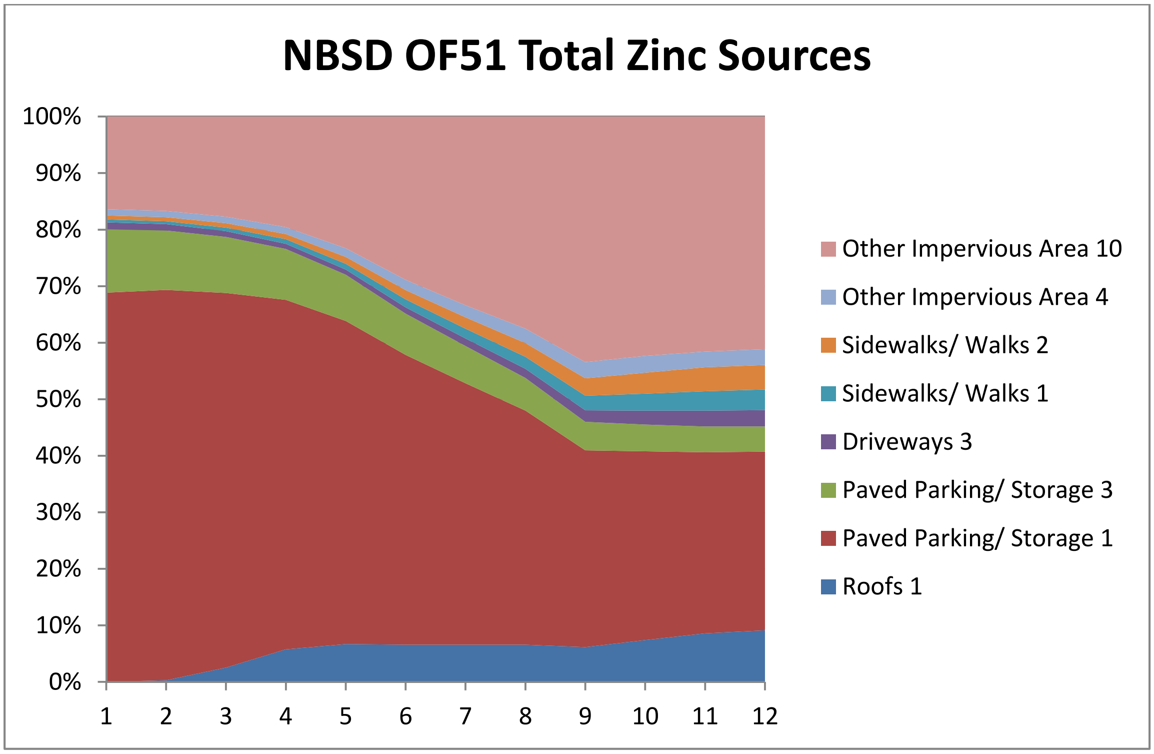
Sub area and portion of total flow	0 to 0.5 inches	0.5 to 1.5 inches	>1.5 inches
NBSD OF51	Paved parking/storage 1 (56 to 68%) Other impervious area 10 (16 to 23%) Paved parking/storage 3 (8 to 11%)	Paved parking/storage 1 (41 to 56%) Other impervious area 10 (23 to 37%)	Other impervious area 10 (37 to 41%) Paved parking/storage 1 (31 to 41%)
NBSD OF70	Paved parking/storage 1 (33 to 43%) Paved parking/storage 1, comer. (13 to 15%) Paved parking/storage 3 (9 to 13%)	Paved parking/storage 1 (21 to 33%) Paved parking/storage 1, comer. (15 to 16%) Roofs 1, comer, (12 to 17%)	Paved parking/storage 1 (14 to 21%) Roofs 1, comer, (18 to 20%) Paved parking/storage 1, comer. (15 to 16%)
NBSD OF72	Paved parking/storage1 (42 to 45%) Roofs 1 (22 to 25%) Roofs3 (14 to 17%)	Paved parking/storage 1 (42%) Roofs 1 (22%) Roofs3 (14%)	Paved parking/storage 1 (42%) Roofs 1 (21 to 22%) Roofs3 (14%)
NBSD OF73	Paved parking/storage 1 (37 to 42%) Roofs 3 (21 to 24%) Roofs 1 (21 to 22%)	Paved parking/storage 1 (37%) Roofs 1 (22%) Roofs 3 (20%)	Paved parking/storage 1 (36 to 37%) Roofs 1 (22%) Roofs 3 (20%) Street 1 (10%)
Sierra Pier	Other impervious areas 4 (31 to 49%) Other impervious areas 3 (8 to 18%) Paved parking/storage 1 (7 to 20%) Other impervious areas 10 (5 to 11%) Roofs 1 (5 to 23%) Roofs 6 (3 to 12%)	Other impervious areas 4 (49 to 52%) Other impervious areas 3 (18 to 20%) Other impervious areas 10 (11 to 12%)	Other impervious areas 4 (47 to 52%) Other impervious areas 3 (20 to 23%) Other impervious areas 10 (13 to 15%)

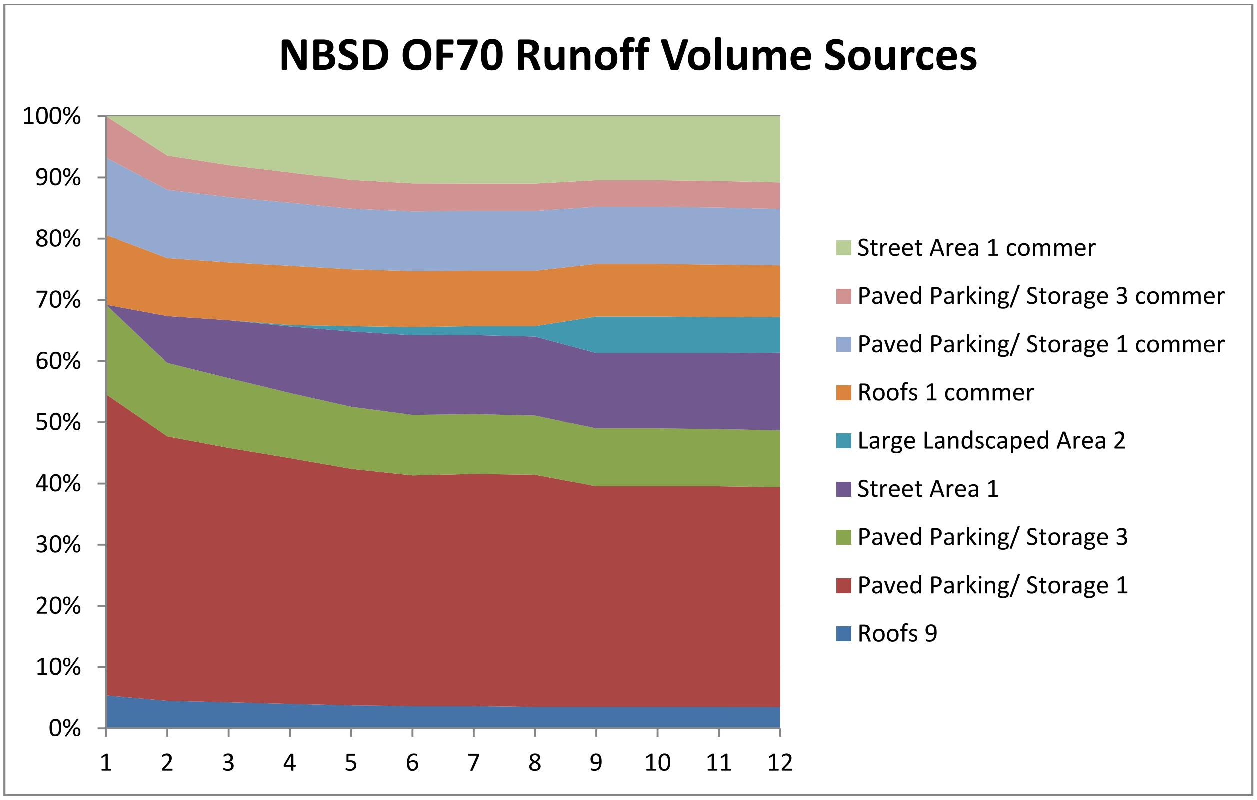
The following figures are graphical representations of these source area contribution data by rain depth.

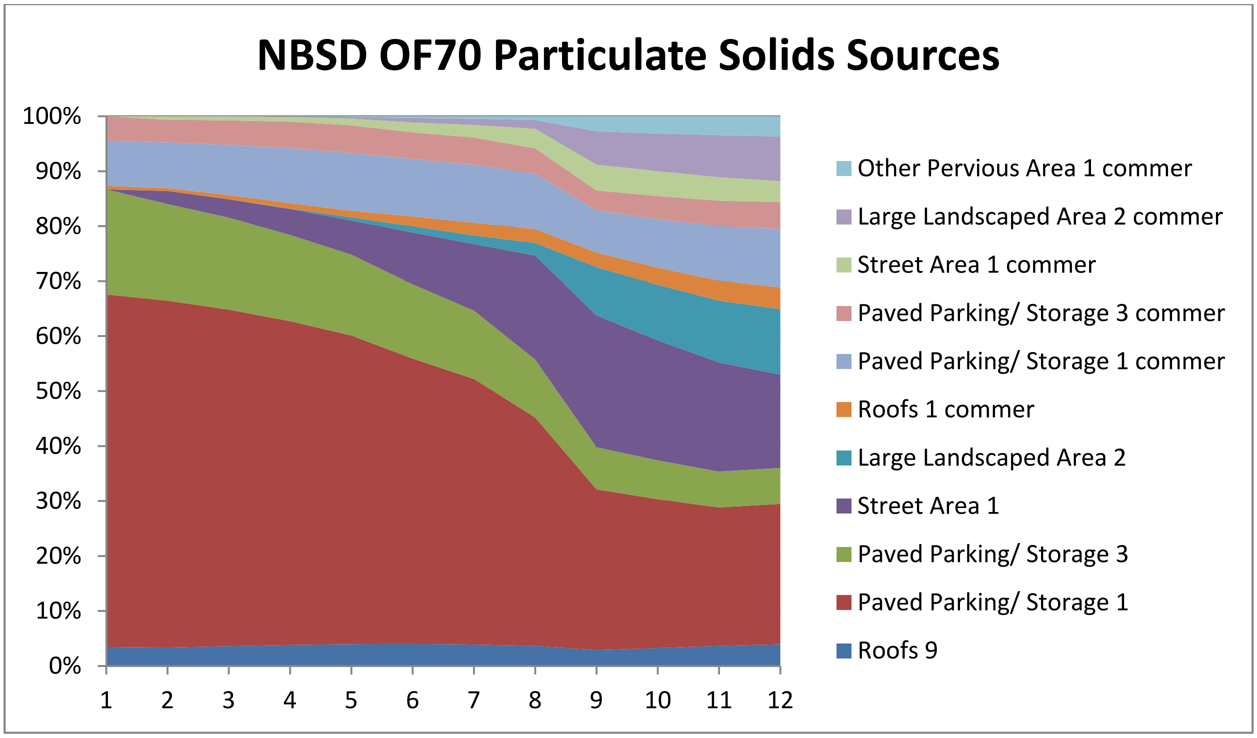

NBSD OF51 Runoff Volume Sources
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1
2
3
4
5
6
7
8
9
10
11
12
Other Impervious Area 10
Large Landscaped Area 2 (other)
Large Landscaped Area 1
Sidewalks/ Walks 2
Sidewalks/ Walks 1
Driveways 3
Paved Parking/ Storage 3
Paved Parking/ Storage 1
Roofs 1

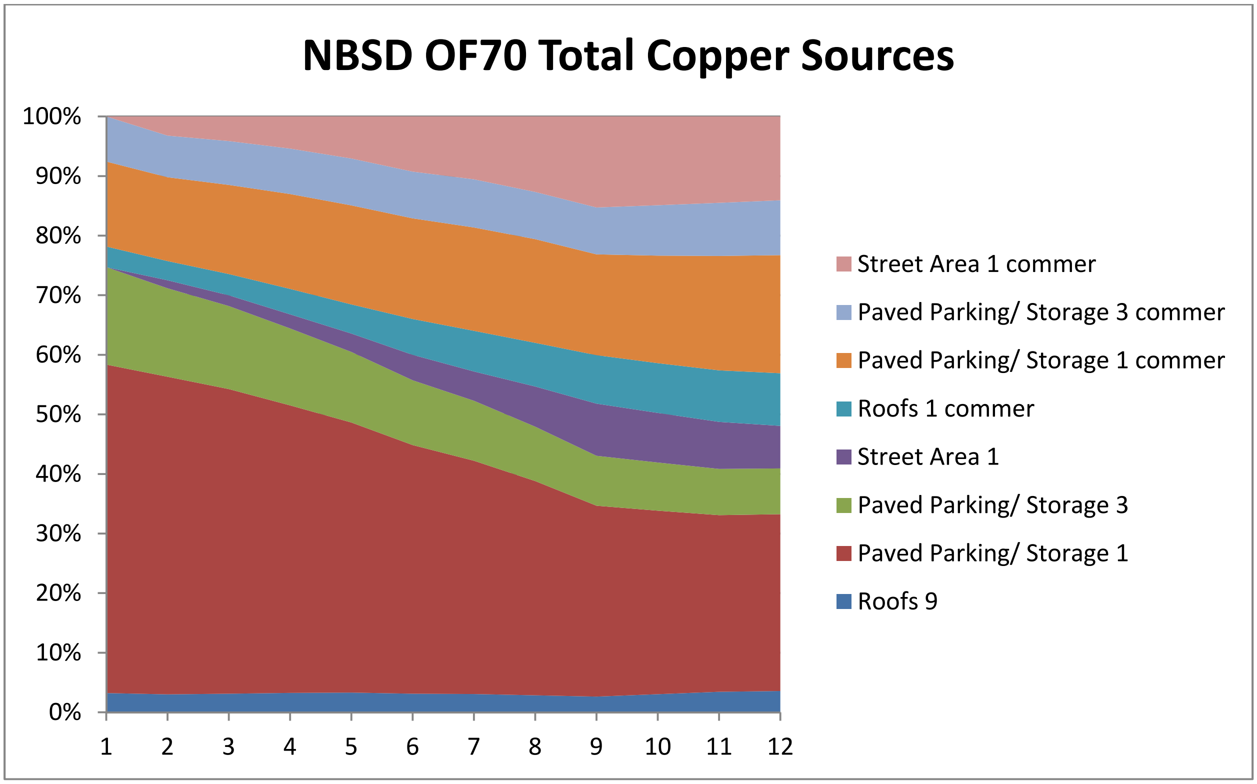

NBSD OF51 Particulate Solids Sources
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1
2
3
4
5
6
7
8
9
10
11
12
Other Impervious Area 10
Large Landscaped Area 2 (other)
Large Landscaped Area 1
Sidewalks/ Walks 2
Sidewalks/ Walks 1
Driveways 3
Paved Parking/ Storage 3
Paved Parking/ Storage 1
Roofs 1

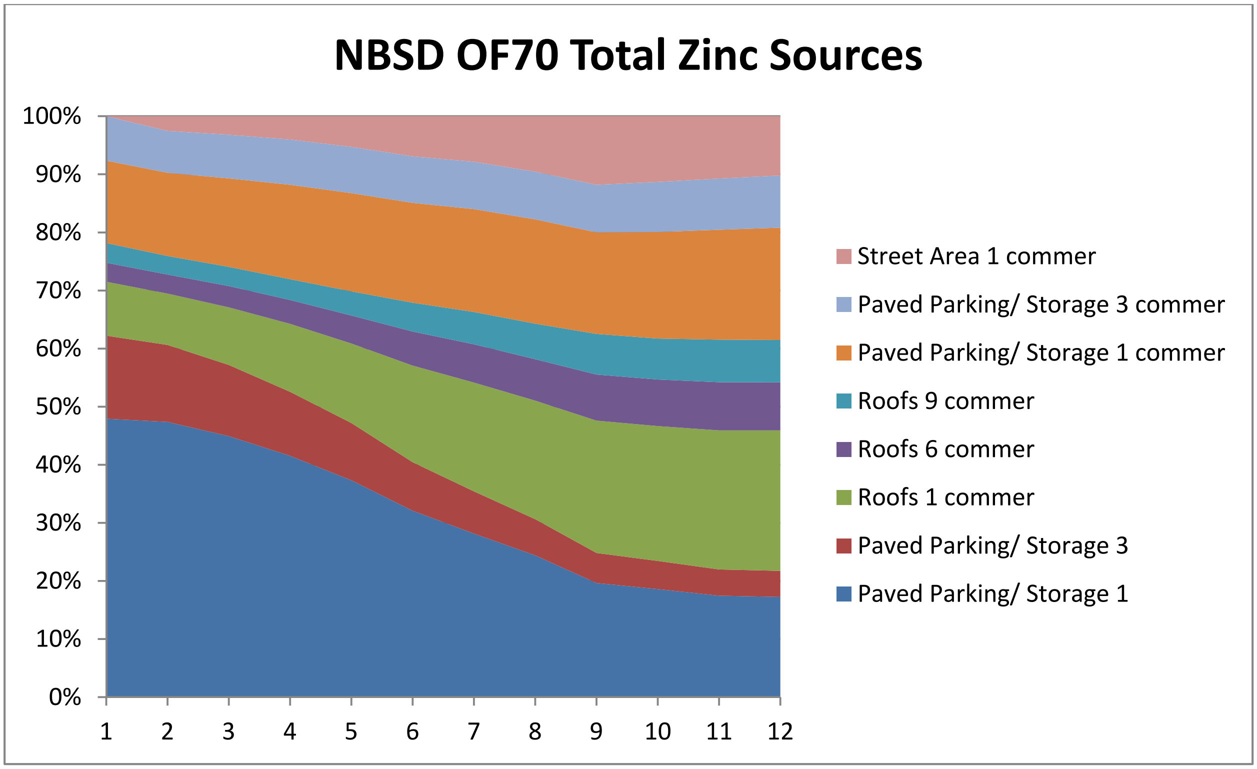

NBSD OF51 Total Copper Sources
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1
2
3
4
5
6
7
8
9
10
11
12
Other Impervious Area 10
Other Impervious Area 4
Large Landscaped Area 1
Sidewalks/ Walks 2
Sidewalks/ Walks 1
Driveways 3
Paved Parking/ Storage 3
Paved Parking/ Storage 1
Roofs 1

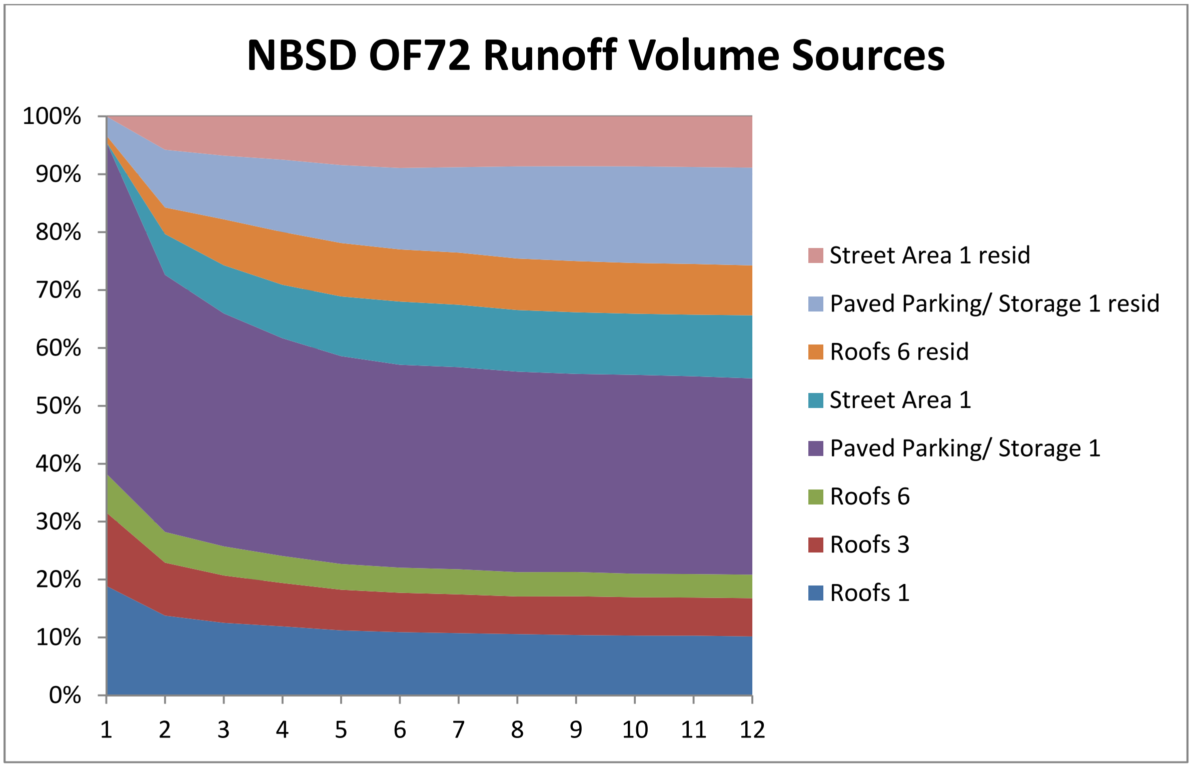

NBSD OF51 Total Zinc Sources
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1
2
3
4
5
6
7
8
9
10
11
12
Other Impervious Area 10
Other Impervious Area 4
Sidewalks/ Walks 2
Sidewalks/ Walks 1
Driveways 3
Paved Parking/ Storage 3
Paved Parking/ Storage 1
Roofs 1

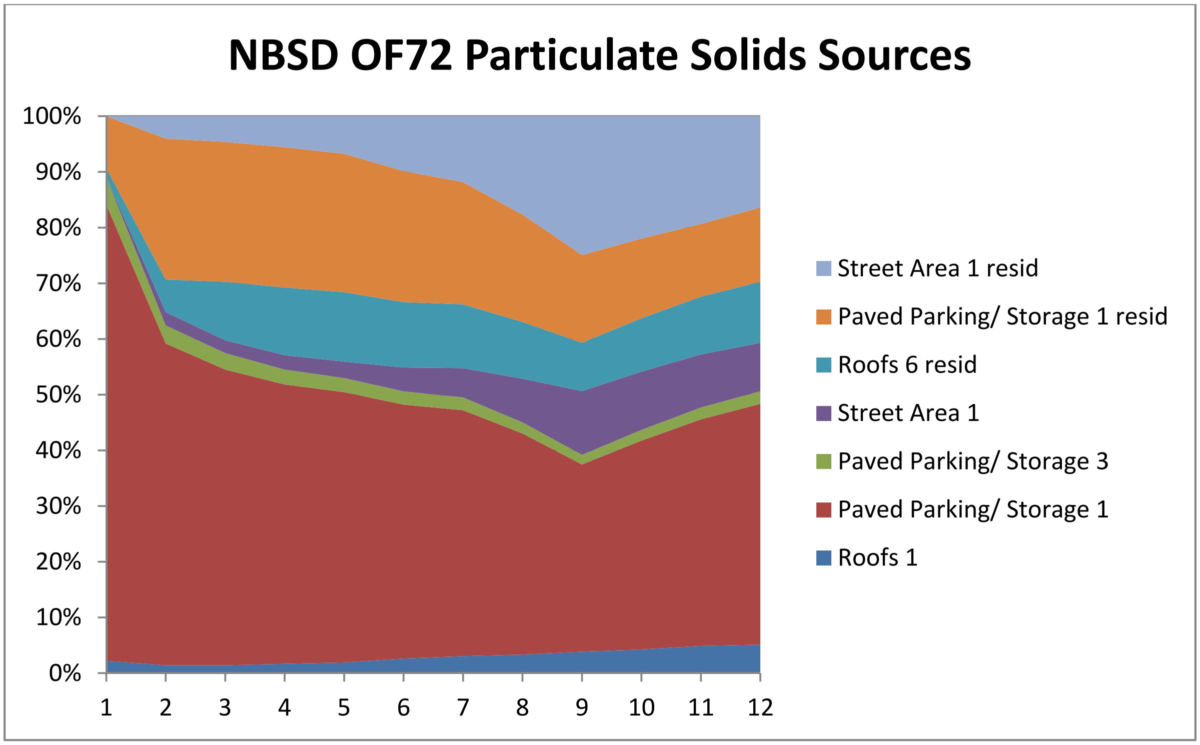

NBSD OF70 Runoff Volume Sources
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1
2
3
4
5
6
7
8
9
10
11
12
Street Area 1 commer
Paved Parking/ Storage 3 commer
Paved Parking/ Storage 1 commer
Roofs 1 commer
Large Landscaped Area 2
Street Area 1
Paved Parking/ Storage 3
Paved Parking/ Storage 1
Roofs 9

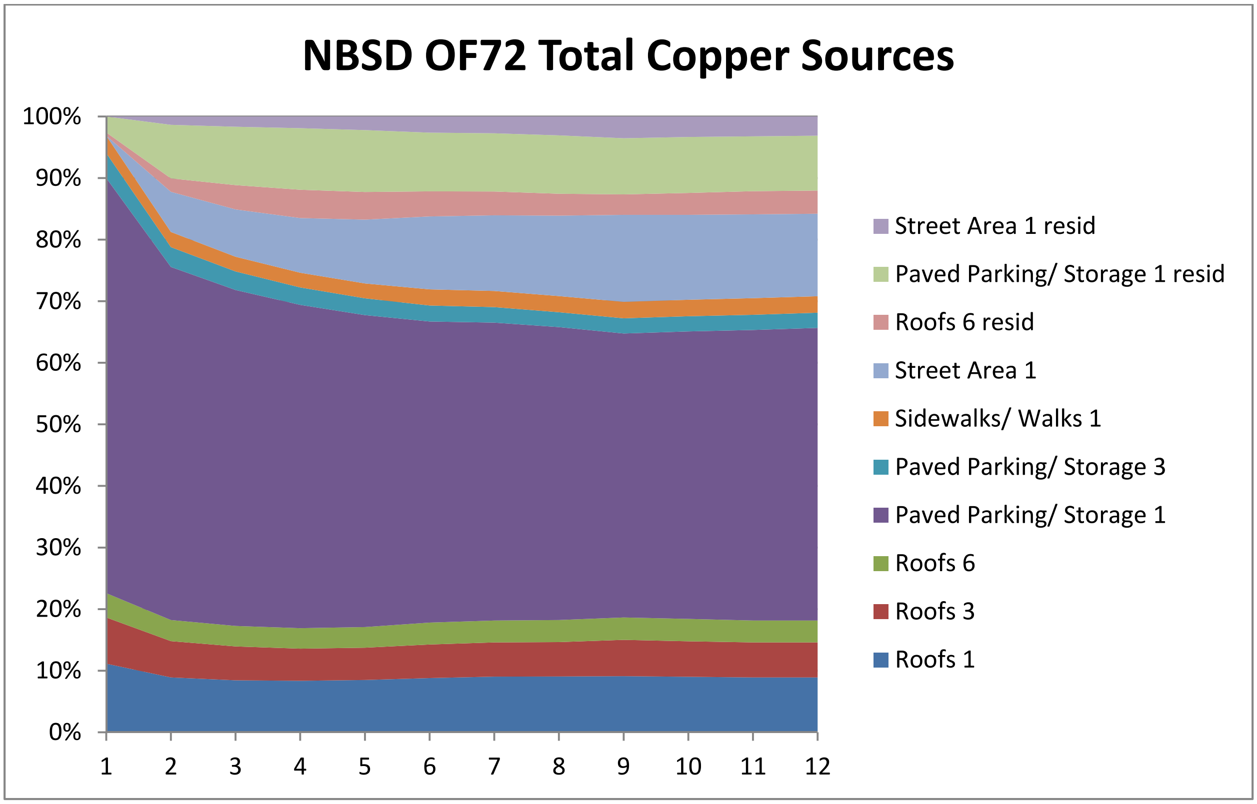

NBSD OF70 Particulate Solids Sources
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1
2
3
4
5
6
7
8
9
10
11
12
Other Pervious Area 1 commer
Large Landscaped Area 2 commer
Street Area 1 commer
Paved Parking/ Storage 3 commer
Paved Parking/ Storage 1 commer
Roofs 1 commer
Large Landscaped Area 2
Street Area 1
Paved Parking/ Storage 3
Paved Parking/ Storage 1
Roofs 9

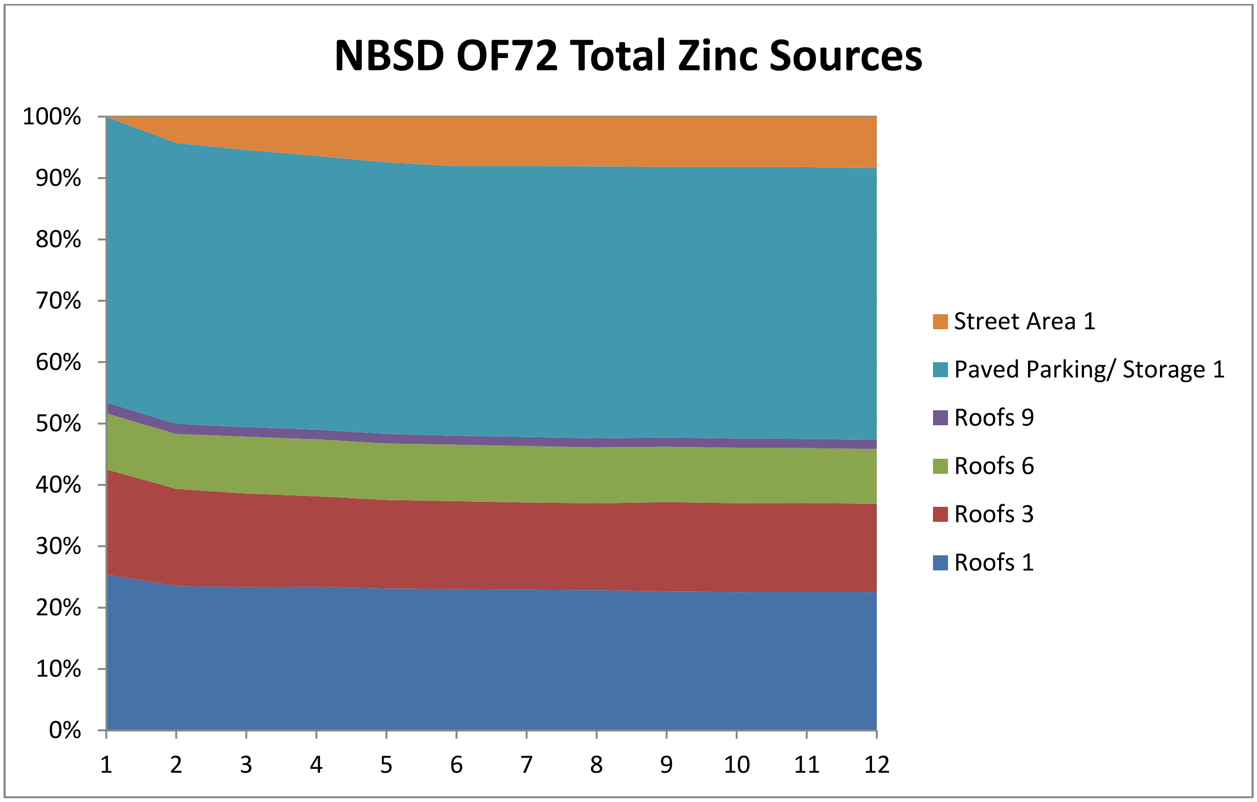

NBSD OF70 Total Copper Sources
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1
2
3
4
5
6
7
8
9
10
11
12
Street Area 1 commer
Paved Parking/ Storage 3 commer
Paved Parking/ Storage 1 commer
Roofs 1 commer
Street Area 1
Paved Parking/ Storage 3
Paved Parking/ Storage 1
Roofs 9


NBSD OF70 Total Zinc Sources
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1
2
3
4
5
6
7
8
9
10
11
12
Street Area 1 commer
Paved Parking/ Storage 3 commer
Paved Parking/ Storage 1 commer
Roofs 9 commer
Roofs 6 commer
Roofs 1 commer
Paved Parking/ Storage 3
Paved Parking/ Storage 1


NBSD OF72 Runoff Volume Sources
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1
2
3
4
5
6
7
8
9
10
11
12
Street Area 1 resid
Paved Parking/ Storage 1 resid
Roofs 6 resid
Street Area 1
Paved Parking/ Storage 1
Roofs 6
Roofs 3
Roofs 1


NBSD OF72 Particulate Solids Sources


NBSD OF72 Total Copper Sources


NBSD OF72 Total Zinc Sources
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1
2
3
4
5
6
7
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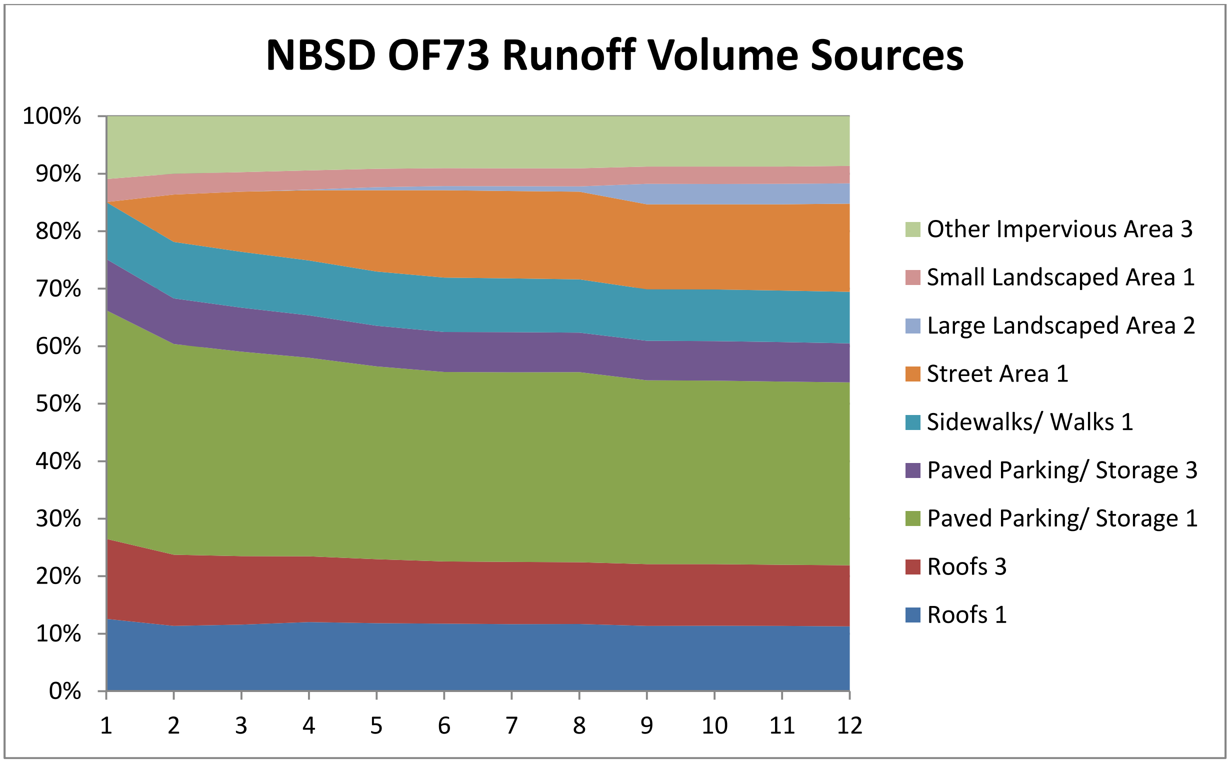
12
Street Area 1
Paved Parking/ Storage 1
Roofs 9
Roofs 6
Roofs 3
Roofs 1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100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
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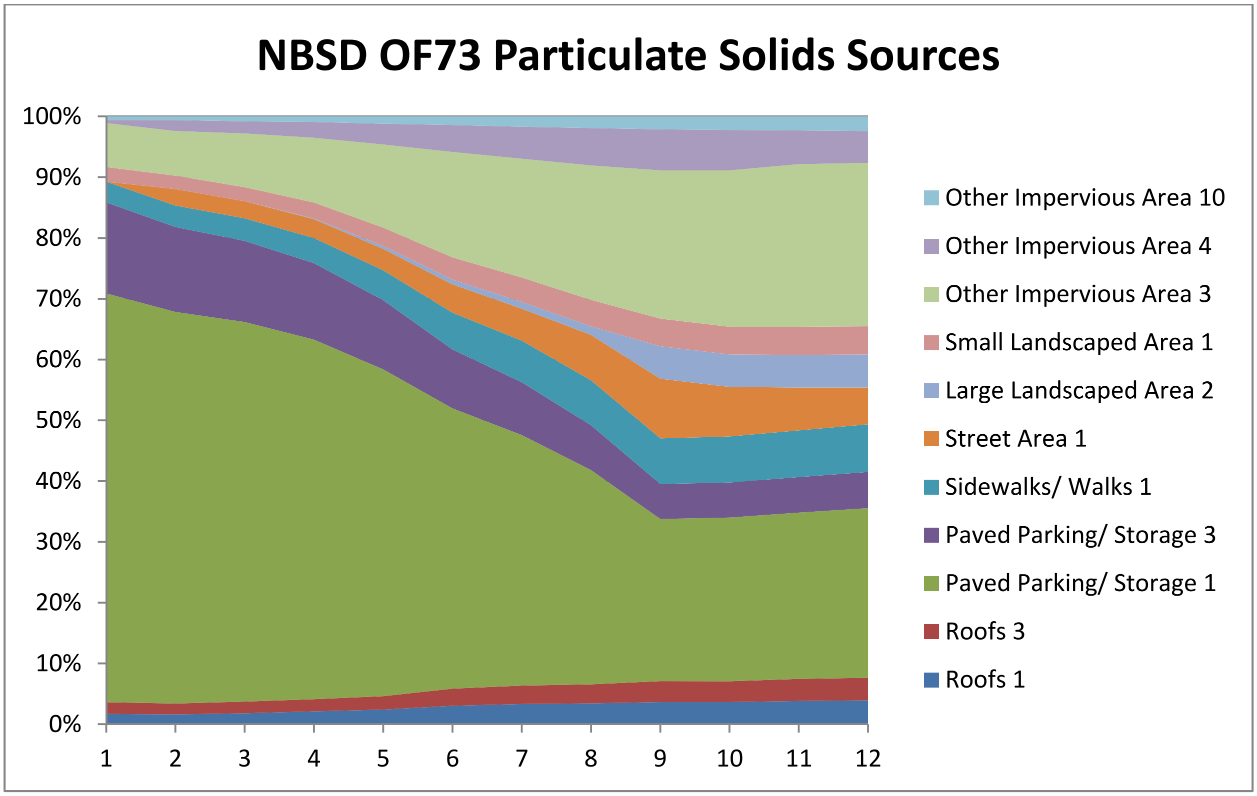
11
12
Other Impervious Area 3
Small Landscaped Area 1
Large Landscaped Area 2
Street Area 1
Sidewalks/ Walks 1
Paved Parking/ Storage 3
Paved Parking/ Storage 1
Roofs 3
Roofs 1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100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
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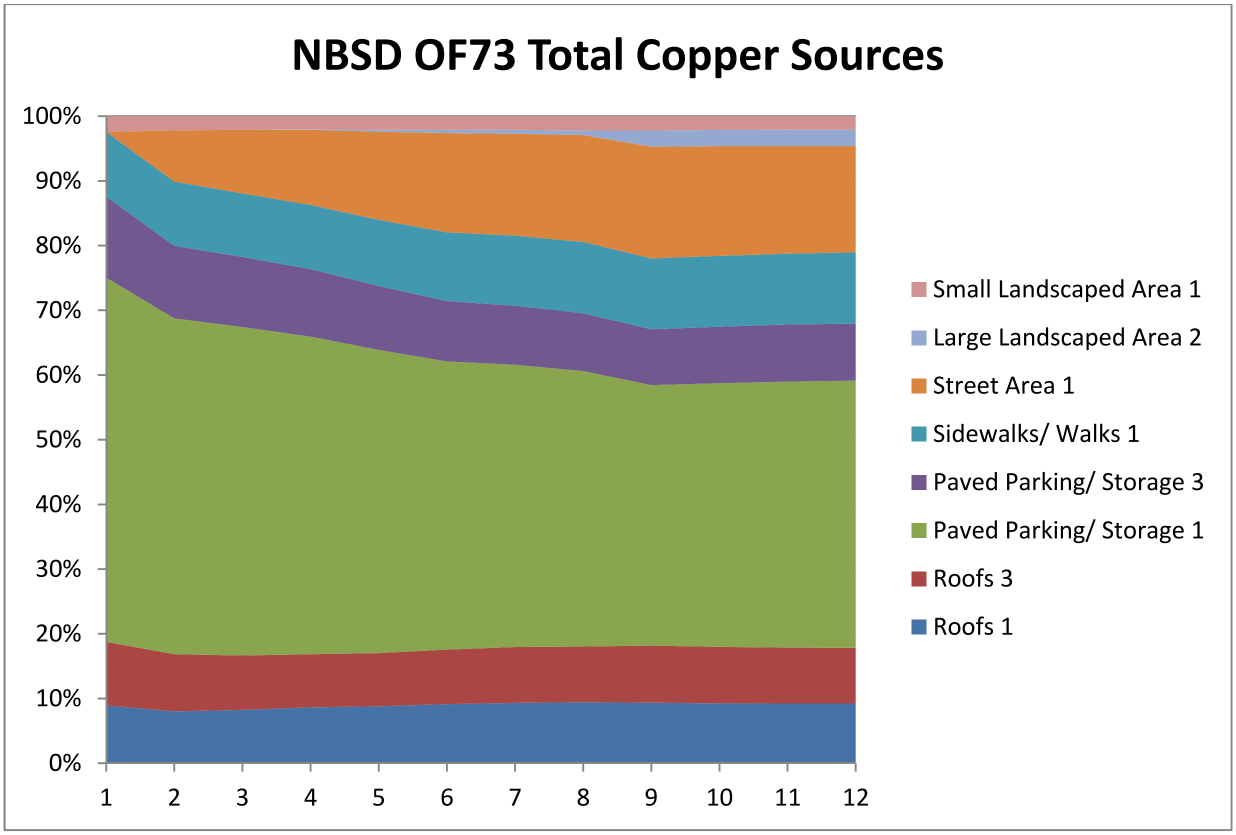
11
12
Other Impervious Area 10
Other Impervious Area 4
Other Impervious Area 3
Small Landscaped Area 1
Large Landscaped Area 2
Street Area 1
Sidewalks/ Walks 1
Paved Parking/ Storage 3
Paved Parking/ Storage 1
Roofs 3
Roofs 1


NBSD OF73 Total Copper Sources
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90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
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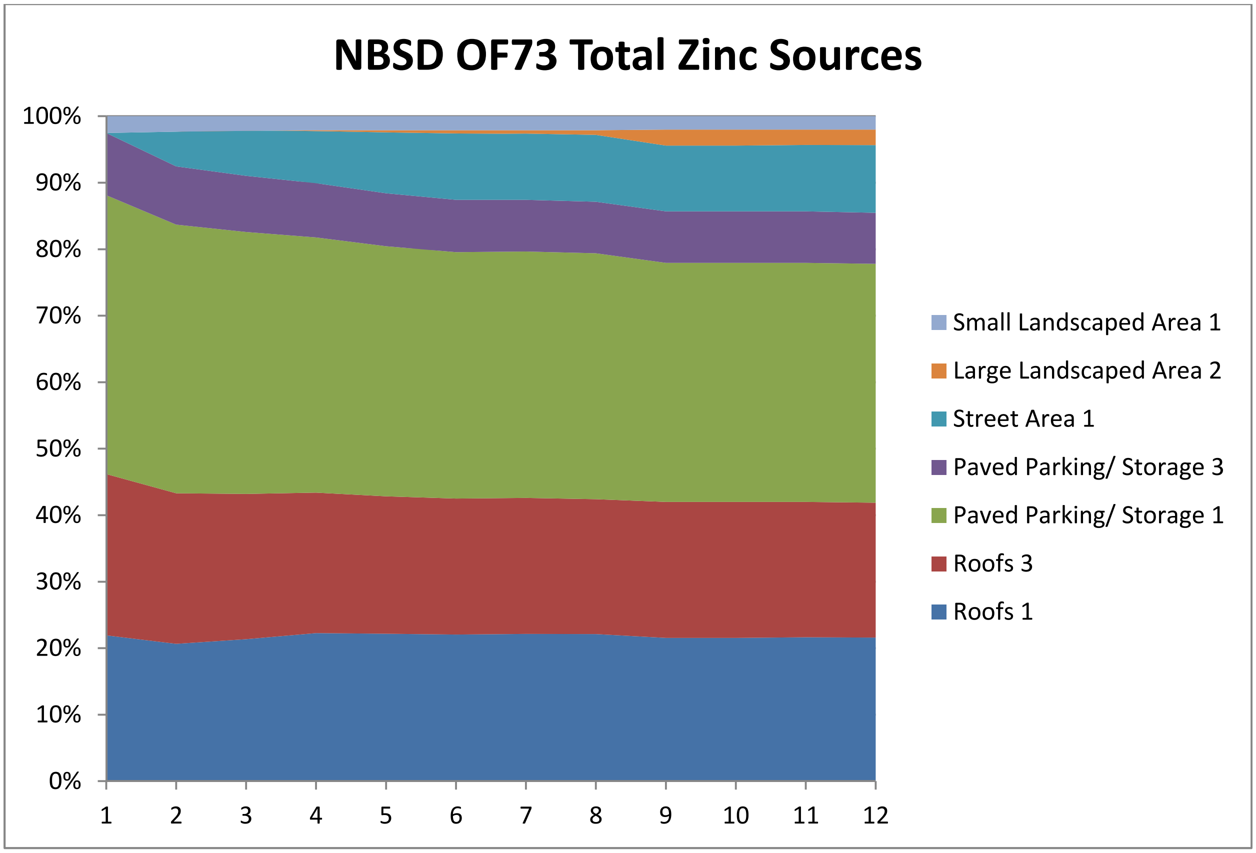
11
12
Small Landscaped Area 1
Large Landscaped Area 2
Street Area 1
Sidewalks/ Walks 1
Paved Parking/ Storage 3
Paved Parking/ Storage 1
Roofs 3
Roofs 1


NBSD OF73 Total Zinc Sources
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
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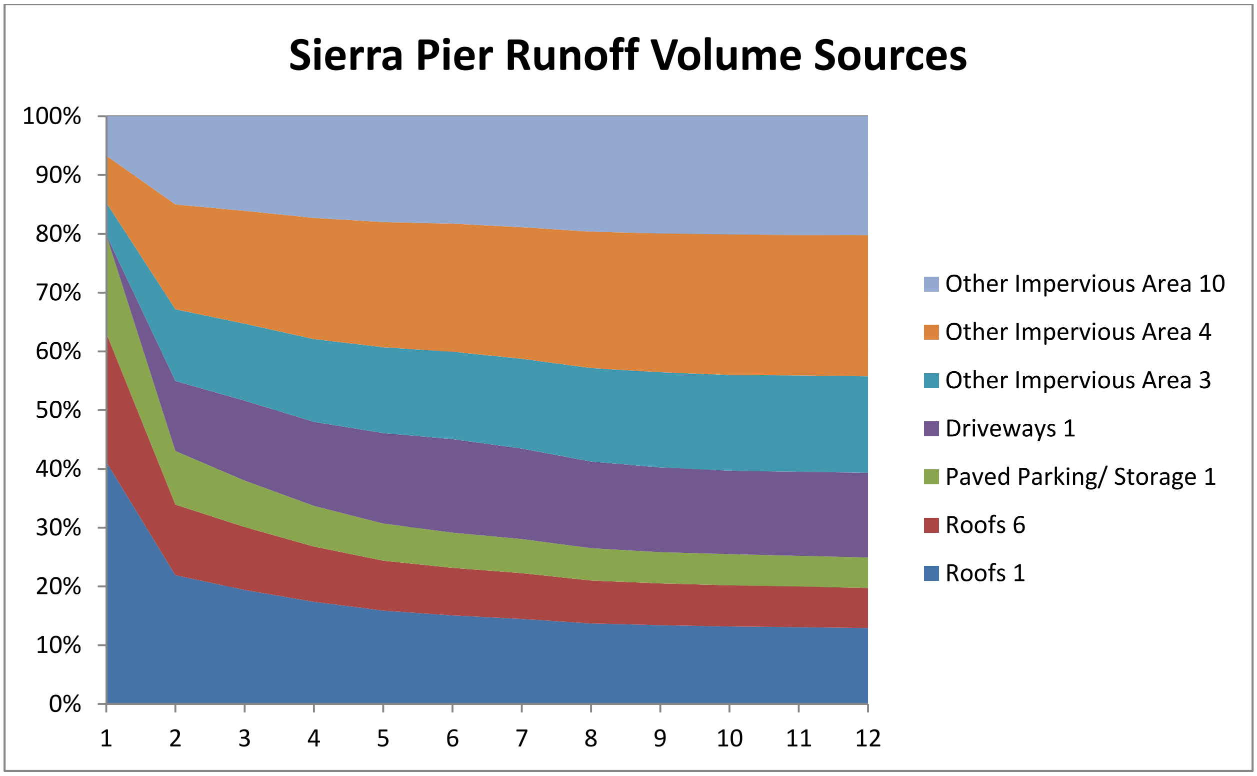
Small Landscaped Area 1
Large Landscaped Area 2
Street Area 1
Paved Parking/ Storage 3
Paved Parking/ Storage 1
Roofs 3
Roofs 1


Sierra Pier Runoff Volume Sources
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
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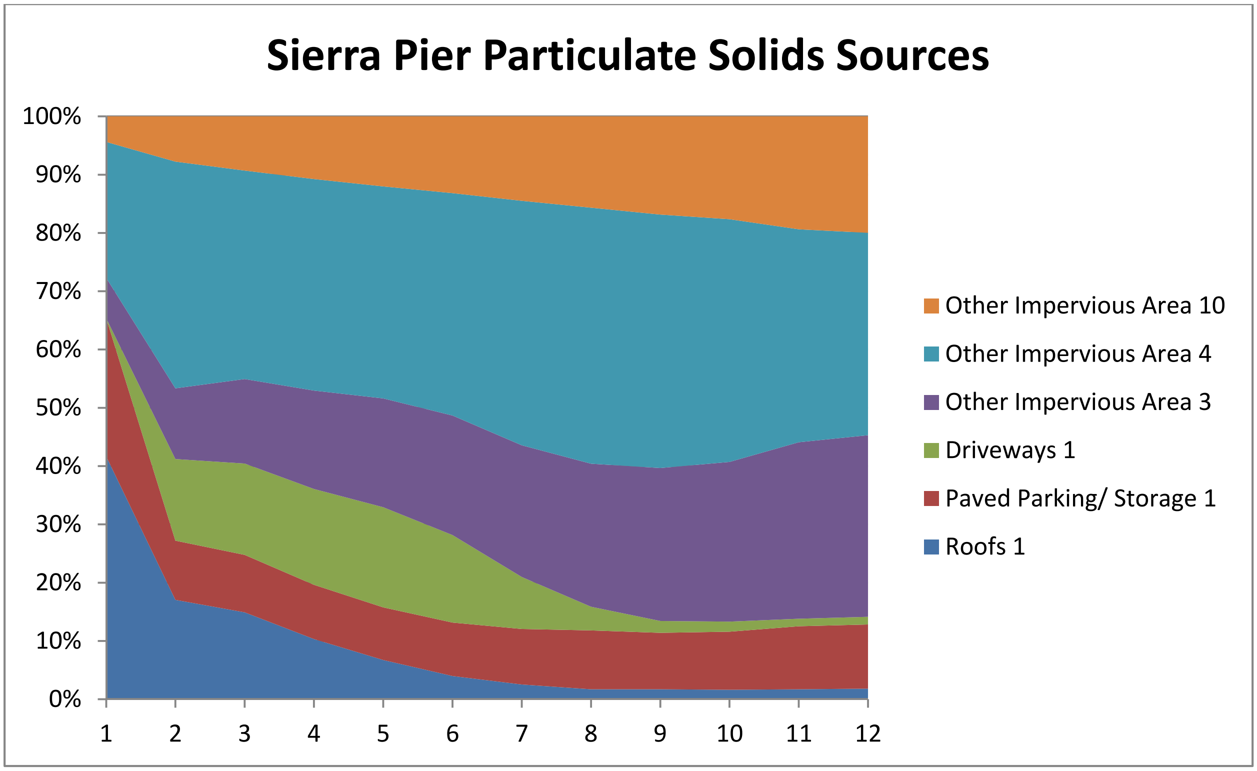
Other Impervious Area 10
Other Impervious Area 4
Other Impervious Area 3
Driveways 1
Paved Parking/ Storage 1
Roofs 6
Roofs 1


Sierra Pier Particulate Solids Sources
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
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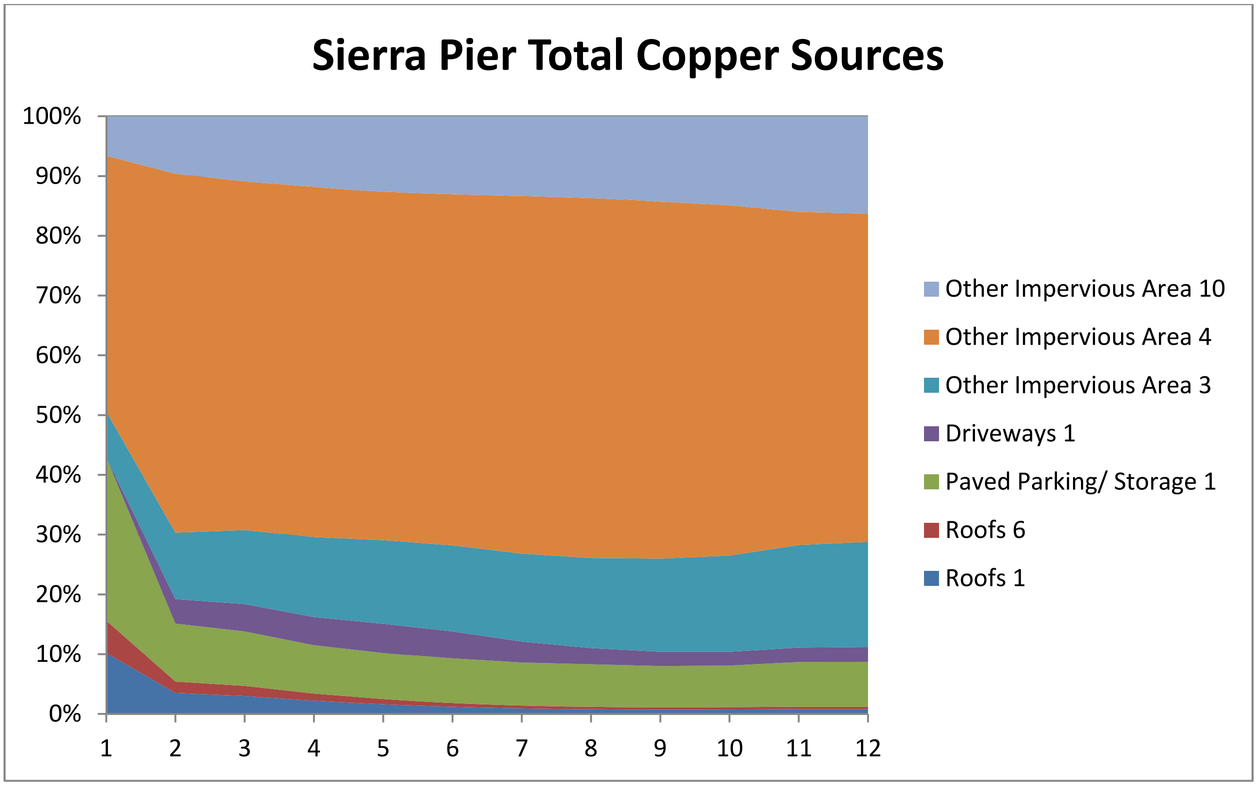
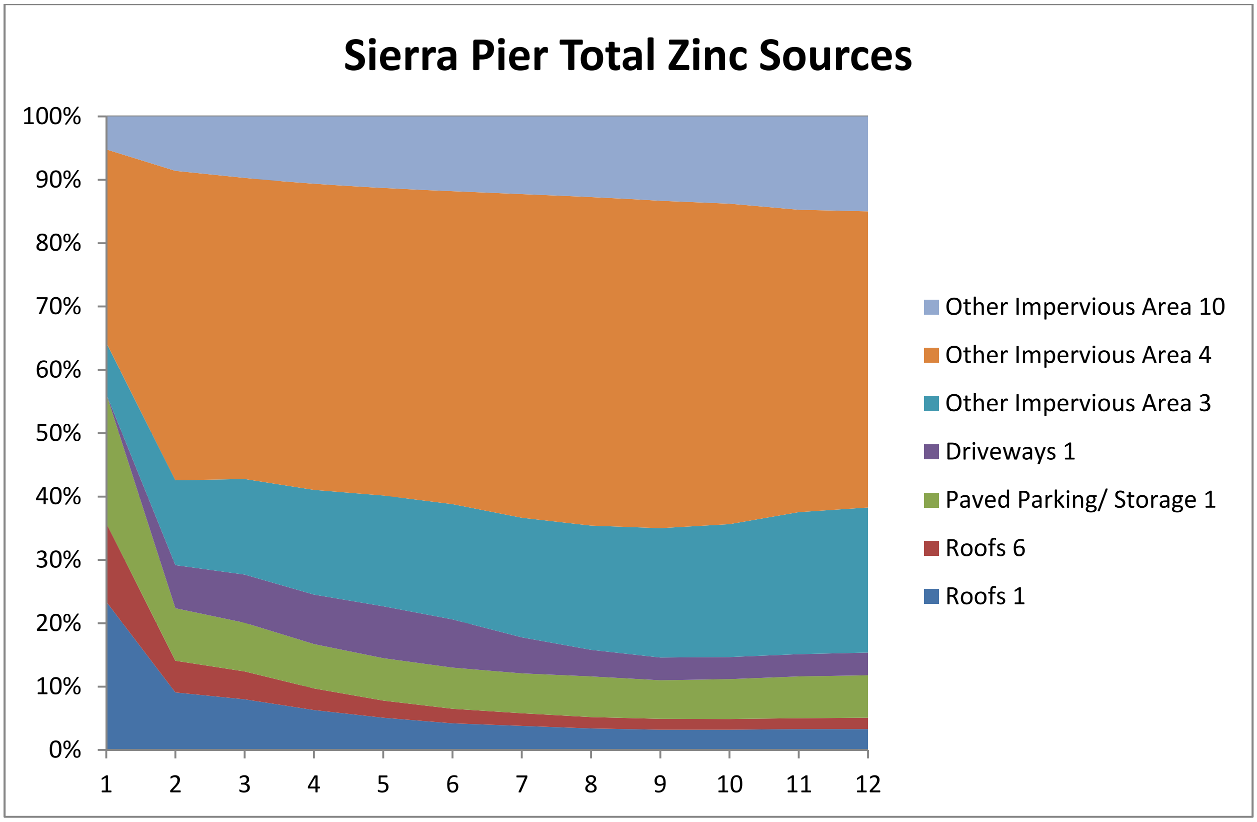
Other Impervious Area 10
Other Impervious Area 4
Other Impervious Area 3
Driveways 1
Paved Parking/ Storage 1
Roofs 1


Sierra Pier Total Copper Sources


Sierra Pier Total Zinc Sources

Virginia Naval Facility Flow and Pollutant Sources

The following tables and figures summarize the flow and pollutant sources for the two Virginia bases examined during 2013.

Source Area Categories for Little Creek Source Contribution Analyses

Source Area Label	Description for Navy analyses	WinSLAMM source #	VA Little Creek OF07 (Naval industrial)	VA St Juliennes OF40&41 (Naval industrial)
Roofs 1	Roofs Flat - connected	1		0.04
Roofs 3	Roofs Flat - disconnected	3		0.06
Roofs 6	Roofs Pitched - connected	6	0.26	0.24
Roofs 9	Roofs Pitched - disconnected	9		0.2
Paved parking 1	Paved parking-connected	13		0.41
Paved parking 3	Paved parking-disconnected	15		2.42
Driveways 3	Driveways/loading dock -disconnected	27		0.1
Sidewalks 2	Sidewalks - disconnected	32		0.02
Streets 1	Streets - with curb and gutters	37		2.33
Large landscaped areas 2	Landscaping areas /undeveloped areas (silty soils)	46		4.54
Small landscaped areas 2	Landscape/undeveloped areas next to buildings and/or parking lots (compacted silty soils)	51		0.02
Other pervious areas 1	Other pervious infiltration areas (sandy soils)	71	0.46	
Other impervious areas 3	Light laydown paved areas- connected	86		0.92
Other impervious areas 4	Moderate laydown paved areas - connected	87	0.05	0.13
Other non-paved areas 1	Light laydown unpaved - disconnected	99		5.04
Other non-paved areas 2	Moderate laydown unpaved - connected	100		6.74
Other non-paved areas 3	Moderate laydown unpaved - disconnected	101	1.42	
Other impervious areas 10*	Other galvanized materials paved- connected	93	0.82	
Other impervious areas 10*	Other galvanized materials paved- disconnected	93		2.31
	Total Area (acres)		3.01	25.52

* for areas having the same source area designation, use the most common condition, or create another land use for the duplicates

Major flow sources for Virginia Naval Facilities:

Sub area and portion of total flow	0 to 0.5 inches	0.5 to 1.5 inches	>1.5 inches
St. Juliennes	Other non-paved area 2 (33 to 37%) Other non-paved area 1 (25 to 27%) Paved parking 6 (11 to 13%) Other impervious area 10 (11 to 13%)	Other non-paved area 2 (32 to 33%) Other non-paved area 1 (24 to 25%) Paved parking 6 (11%) Other impervious area 10 (11%) Street 1 (10 to 11%)	Other non-paved area 2 (31 to 32%) Other non-paved area 1 (23%) Other impervious area 10 (11%) Street 1 (11%) Paved parking 6 (10 to 11%)
Little Creek	Other non-paved area 3 (47 to 48%) Other impervious area 10 (28 to 29%) Other pervious area 1 (13 to 14%)	Other non-paved area 3 (48%) Other impervious area 10 (28%) Other pervious area 1 (13%)	Other non-paved area 3 (48%) Other impervious area 10 (28%) Other pervious area 1 (13%)

Major particulate solids sources for Virginia Naval Facilities:

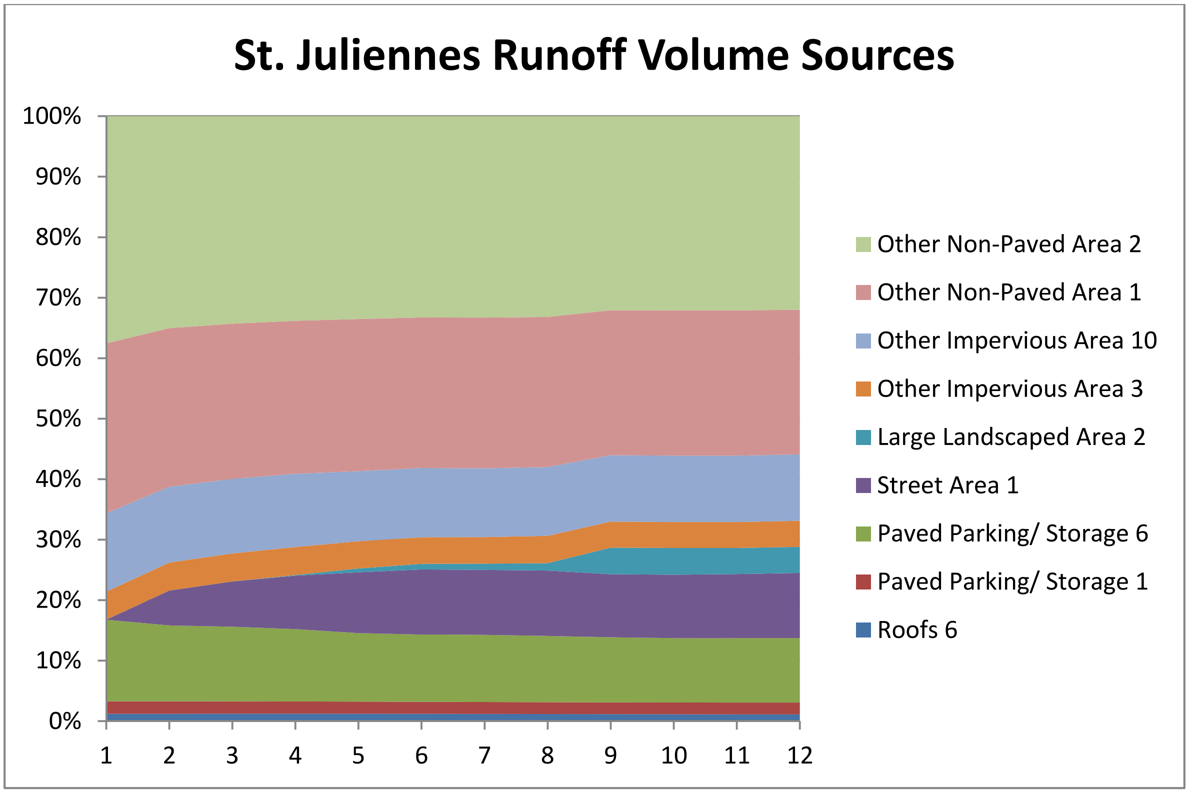
Sub area and portion of total flow	0 to 0.5 inches	0.5 to 1.5 inches	>1.5 inches
St. Juliennes	Other non-paved area 2 (36 to 42%) Other non-paved area 1 (27 to 31%) Paved parking 6 (11 to 16%) Street 1 (0 to 16%)	Other non-paved area 2 (31 to 36%) Other non-paved area 1 (23 to 27%) Street 1 (16 to 26%) Paved parking 6 (9 to 11%)	Other non-paved area 2 (19 to 23%) Other non-paved area 1 (19 to 23%) Street 1 (26 to 29%)
Little Creek	Other non-paved area 3 (70 to 77%) Other impervious area 10 (18 to 19%)	Other non-paved area 3 (54 to 70%) Other impervious area 10 (15 to 19%) Other pervious area 1 (9 to 30%)	Other non-paved area 3 (42 to 54%) Other impervious area 10 (14 to 15%) Other pervious area 1 (30 to 43%)

Major total copper sources for Virginia Naval Facilities:

Sub area and portion of total flow	0 to 0.5 inches	0.5 to 1.5 inches	>1.5 inches
St. Juliennes	Other non-paved area 2 (32 to 34%) Other impervious area 10 (25 to 26%) Other non-paved area 1 (24 to 25%)	Other non-paved area 2 (31 to 32%) Other impervious area 10 (26%) Other non-paved area 1 (23%)	Other non-paved area 2 (29 to 31%) Other impervious area 10 (26 to 28%) Other non-paved area 1 (22 to 23%)
Little Creek	Other impervious area 10 (51 to 53%) Other non-paved area 3 (39%)	Other impervious area 10 (53 to 54%) Other non-paved area 3 (38 to 39%)	Other impervious area 10 (54 to 57%) Other non-paved area 3 (35 to 38%)

Major total zinc sources for Virginia Naval Facilities:

Sub area and portion of total flow	0 to 0.5 inches	0.5 to 1.5 inches	>1.5 inches
St. Juliennes	Other impervious area 10 (54 to 56%) Other non-paved area 2 (21%) Other non-paved area 1 (16%)	Other impervious area 10 (54%) Other non-paved area 2 (21%) Other non-paved area 1 (16%)	Other impervious area 10 (54%) Other non-paved area 2 (21%) Other non-paved area 1 (16%)
Little Creek	Other impervious area 10 (79%) Other non-paved area 3 (18%)	Other impervious area 10 (79%) Other non-paved area 3 (18%)	Other impervious area 10 (79%) Other non-paved area 3 (18%)


St. Juliennes Runoff Volume Sources
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
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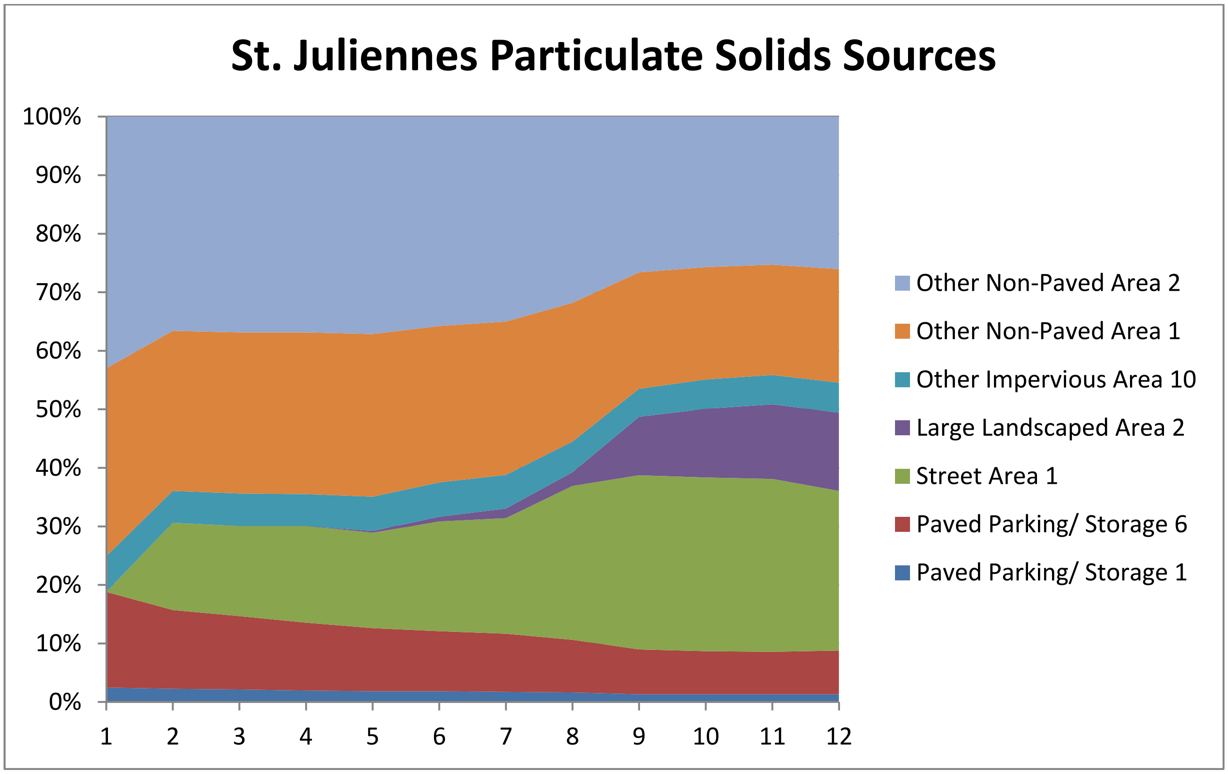
11
12
Other Non-Paved Area 2
Other Non-Paved Area 1
Other Impervious Area 10
Other Impervious Area 3
Large Landscaped Area 2
Street Area 1
Paved Parking/ Storage 6
Paved Parking/ Storage 1
Roofs 6


St. Juliennes Particulate Solids Sources
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
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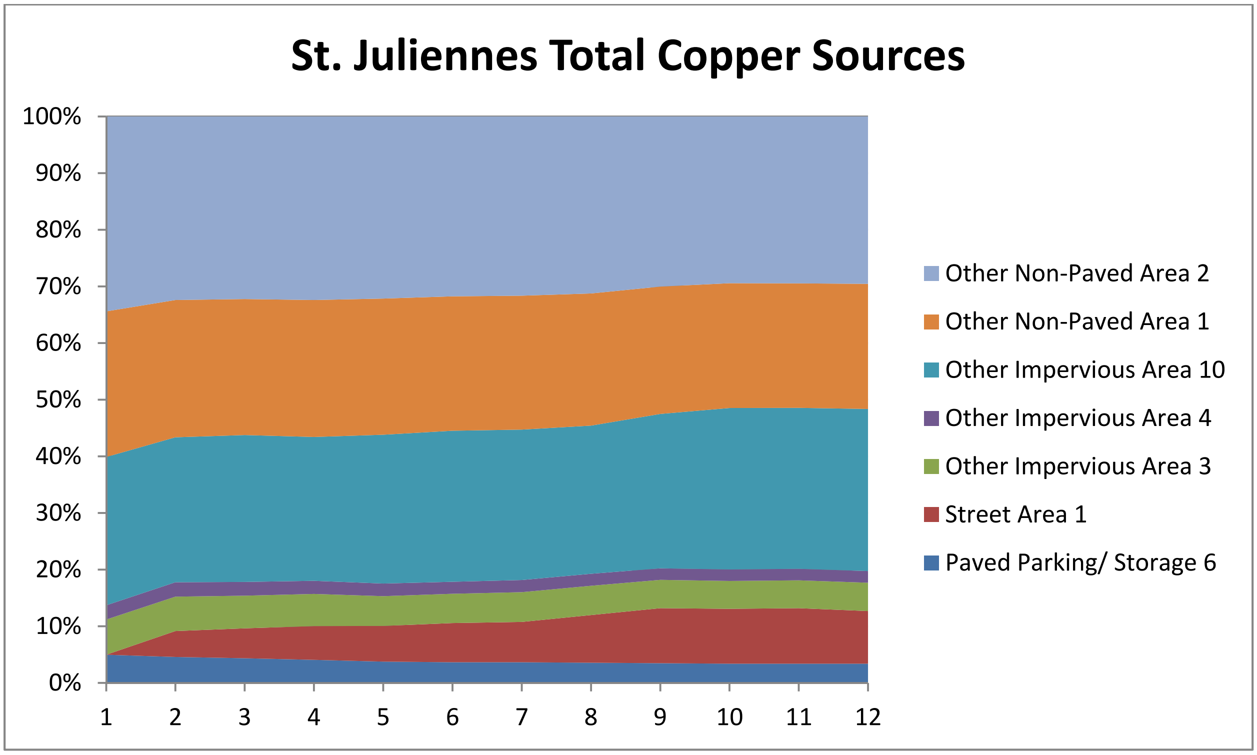
11
12
Other Non-Paved Area 2
Other Non-Paved Area 1
Other Impervious Area 10
Large Landscaped Area 2
Street Area 1
Paved Parking/ Storage 6
Paved Parking/ Storage 1


St. Juliennes Total Copper Sources
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
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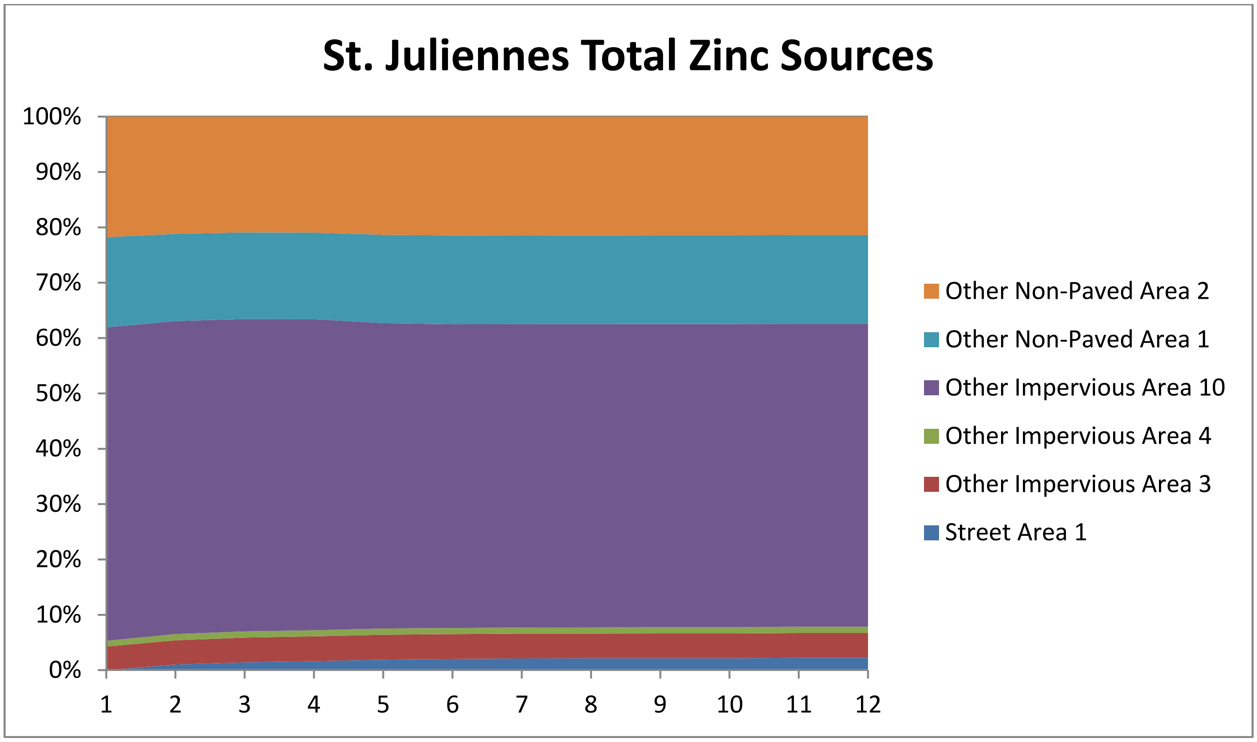
Other Non-Paved Area 2
Other Non-Paved Area 1
Other Impervious Area 10
Other Impervious Area 4
Other Impervious Area 3
Street Area 1
Paved Parking/ Storage 6


St. Juliennes Total Zinc Sources
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
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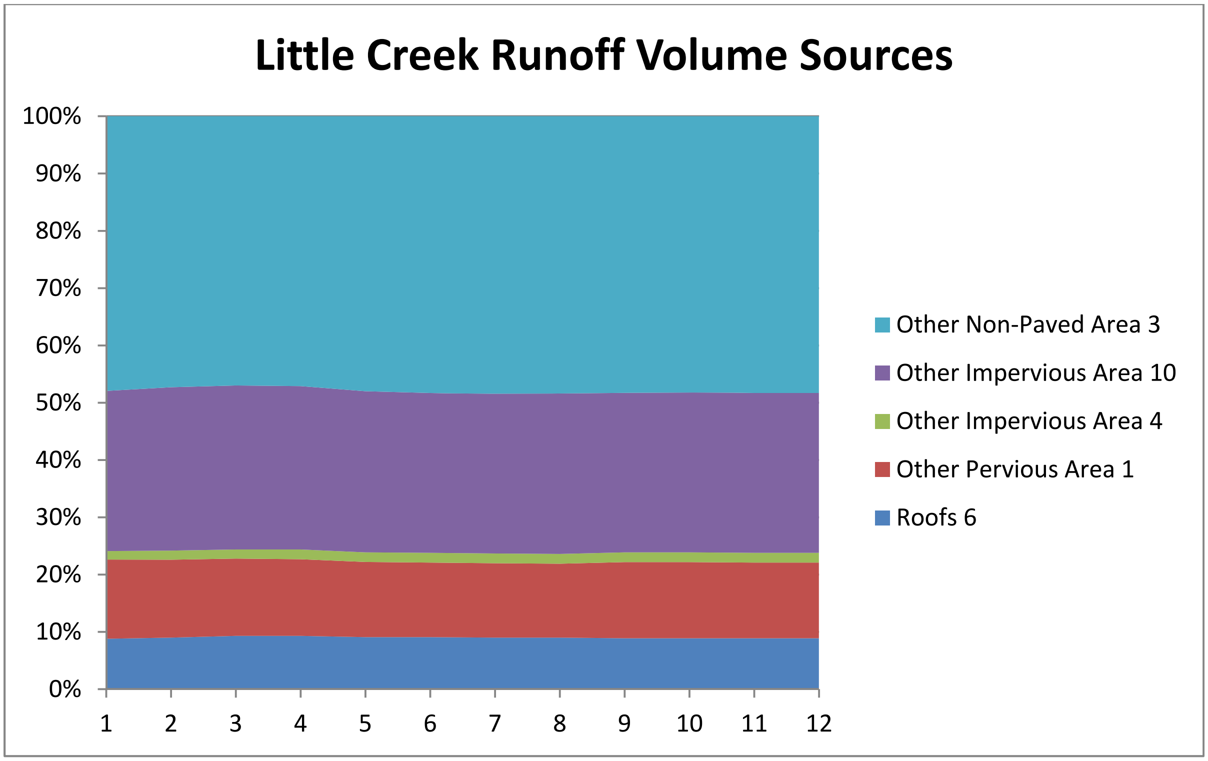
Other Non-Paved Area 2
Other Non-Paved Area 1
Other Impervious Area 10
Other Impervious Area 4
Other Impervious Area 3
Street Area 1


Little Creek Runoff Volume Sources
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1
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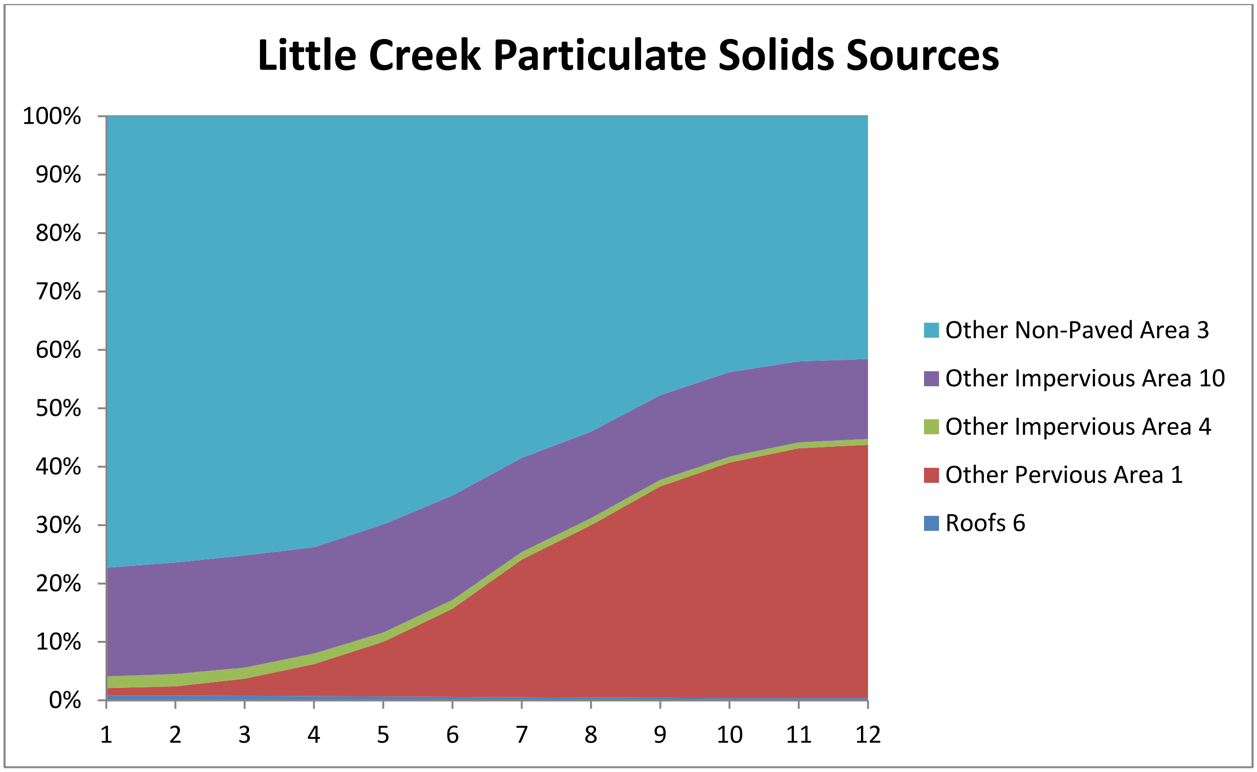
Other Non-Paved Area 3
Other Impervious Area 10
Other Impervious Area 4
Other Pervious Area 1
Roofs 6



Little Creek Particulate Solids Sources
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
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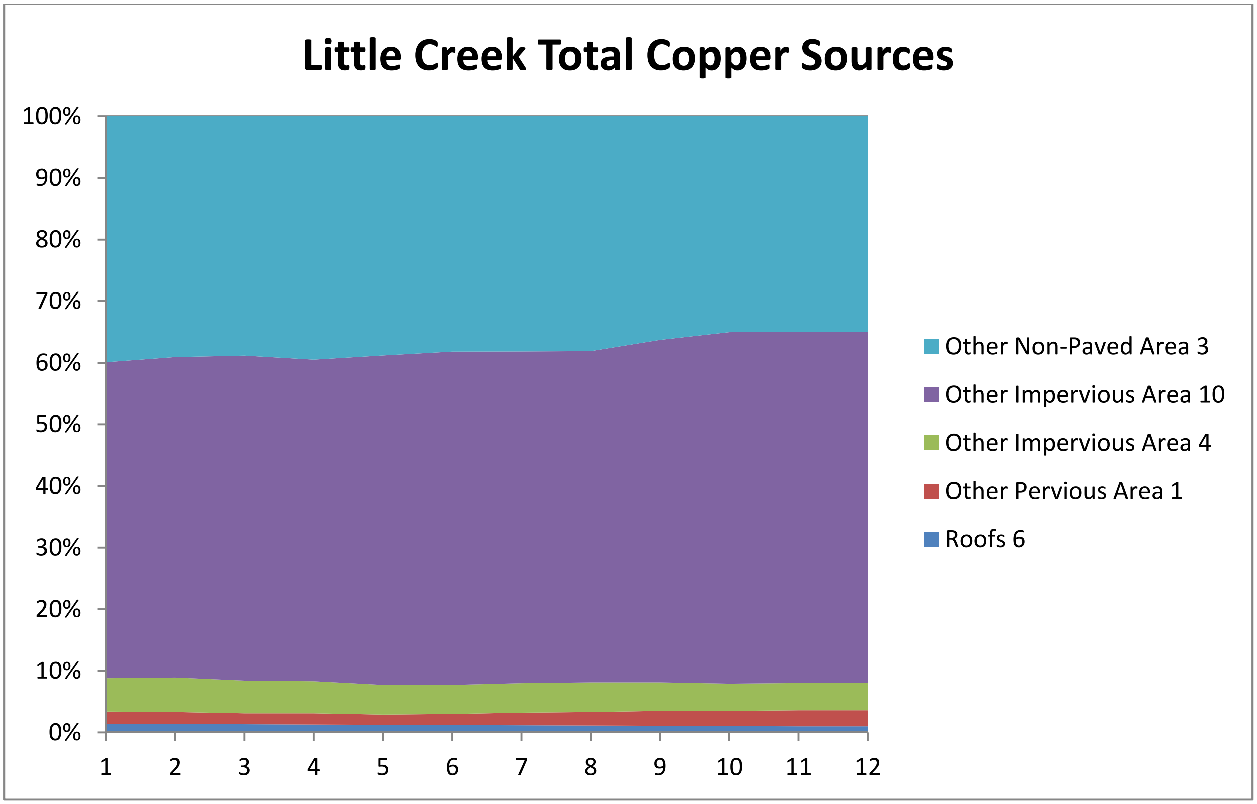
Other Non-Paved Area 3
Other Impervious Area 10
Other Impervious Area 4
Other Pervious Area 1
Roofs 6



Little Creek Total Copper Sources
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
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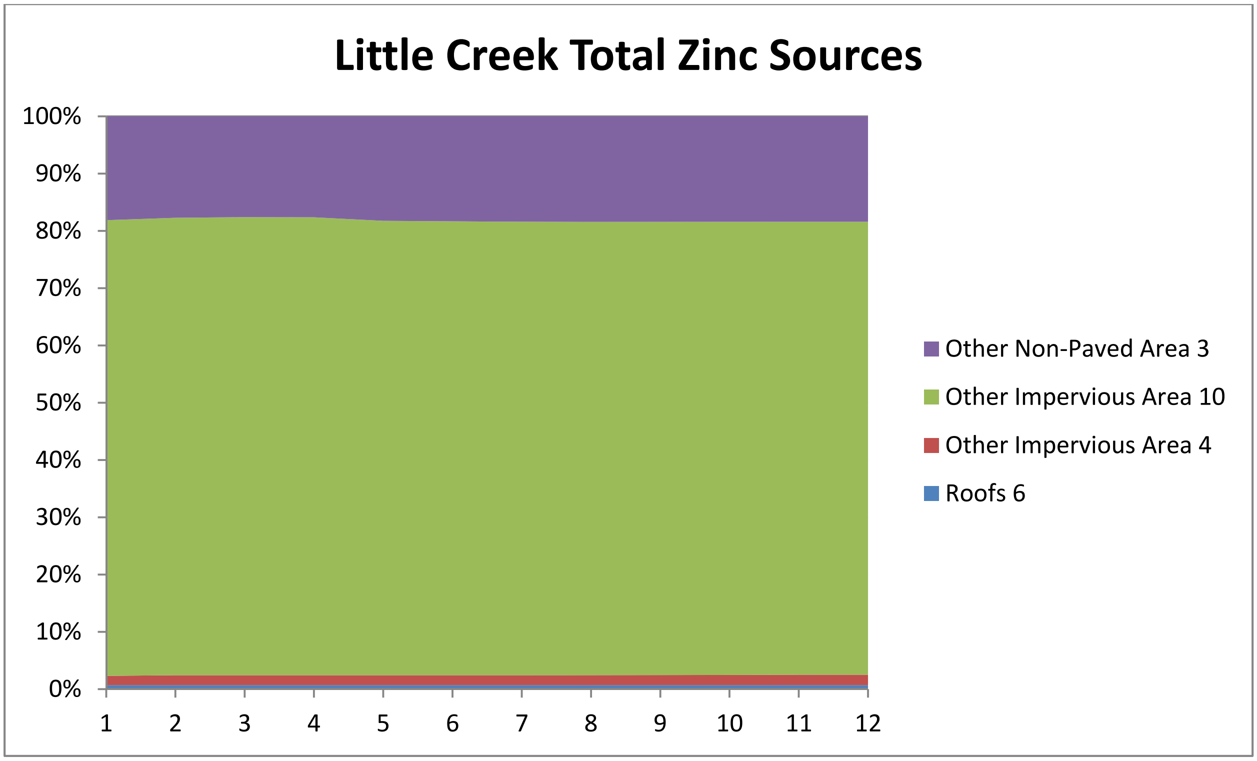
Other Non-Paved Area 3
Other Impervious Area 10
Other Impervious Area 4
Other Pervious Area 1
Roofs 6



Washington Naval Facility Flow and Pollutant Sources

The following tables and figures illustrate and summarize the flow and pollutant sources for the three naval facilities examined during 2013 in the Puget Sound area.

Source Area Categories for Washington Source Contribution Analyses

Source Area Label	Descriptions for Navy Analyses	WinSLAMM source #	WA Bangor OF02 (Naval industrial)	WA Bremerton OF015 (residential)	WA Bremerton OF015 (commercial/ institutional)	WA Bremerton OF015 (Naval industrial)	WA Everett OFA (Naval industrial)
Roofs 1	Roofs Flat - connected	1	14.83	1.14	4.31	3.29	0.16
Roofs 3	Roofs Flat - disconnected	3	1.78	0.05	0.02		
Roofs 6	Roofs Pitched - connected	6	13.43	3.03	1.96	1.8	0.3
Roofs 9	Roofs Pitched - disconnected	9	3.57	0.69	0.1		
Paved parking 1	Paved parking-connected	13	22.18	7.48	9.99	3.62	2.1
Paved parking 3	Paved parking-disconnected	15	21.26				
Unpaved parking 1	Unpaved parking-connected	19	0.03				
Unpaved parking 2	Unpaved parking-disconnected	20	2.35				
Driveways 1	Driveways/loading dock -connected	25	2.23	0.81	1.44	0.73	
Driveways 3	Driveways/loading dock -disconnected	27	1.23	0.2	0.22		
Sidewalks 1	Sidewalks - connected	31	1.19	0.05	1.53	0.06	0.73
Sidewalks 2	Sidewalks - disconnected	32	0.58				
Streets 1	Streets - with curb and gutters	37	100.36	5.36	4.39	2.11	2.56
Streets 2	Streets - with grass swales (need area and average width of streets)	38	45.61				
Large landscaped areas 1	Landscaping areas /undeveloped areas (silty soils)	46	916.1	24.6	15.33	2.07	1.45
Small landscaped areas 1	Landscape/undeveloped areas next to buildings and/or parking lots (compacted silty soils)	51	0.45		0.42		
Other pervious areas 1	Other pervious infiltration areas (sandy soils)	71	269.71	0.07	0.16		0.08
Other impervious areas 3*	Light laydown paved areas- connected	86	7.34	0.02	0.2		6.81
Other impervious areas 3*	Light laydown paved areas- disconnected	86	2.16	0.22			
Other impervious areas 4	Moderate laydown paved areas - connected	87	3.53	0.11	0.29	1.78	0.21
Other impervious areas 4	Moderate laydown paved areas - disconnected	87	0.33	0.45			
Other impervious areas 5	Heavy laydown paved areas- connected	88	0.83		0.37	1.21	0.193
Other impervious areas 5	Heavy laydown paved areas-disconnected	88	0.41				

Source Area Categories for Washington Source Contribution Analyses (continued)

Other non-paved areas 1	Light laydown unpaved - disconnected	99	7.43				
Other non-paved areas 3	Moderate laydown unpaved - disconnected	101	0.33				
Other non-paved areas 5	Heavy laydown unpaved - disconnected	103	0.66				
Other impervious areas 10	Other galvanized materials paved- connected	93			0.15	0.21	0.92
Other impervious areas 10	Other galvanized materials paved- disconnected	93	2.29	0.47	0.55		
	Total Area (acres):		1442.2	44.75	41.43	16.88	15.513

* for areas having the same source area designation, use the most common condition, or create another land use for the duplicates

Major flow sources for Washington Naval Facilities:

Sub area and portion of total flow	0 to 0.5 inches	0.5 to 1.5 inches	>1.5 inches
Bangor	Paved parking 1 (8 to 21%) Paved parking 3 (7 to 19%) Roofs 1 (6 to 15%) Roofs 6 (5 to 12%) Street 1 (0 to 34%) Street 2 (0 to 16%)	Street 1 (32 to 34%) Street 2 (15%) Large landscaped area 2 (10 to 17%)	Street 1 (22 to 32%) Large landscaped area 2 (17 to 43%) Street 2 (10 to 15%)
Bremerton	Paved parking 1, comer. (17 to 24%) Paved parking 1, resid. (13 to 18%)	Paved parking 1, comer. (16 to 17%) Paved parking 1, resid. (12 to 13%)	Paved parking 1, comer. (15 to 16%) Paved parking 1, resid. (11 to 12%)
Everett	Other impervious area 3 (49 to 60%) Paved parking 1 (15 to 18%) Street 1 (0 to 16%)	Other impervious area 3 (49%) Street 1 (16 to 17%) Paved parking 1 (15%)	Other impervious area 3 (48 to 49%) Street 1 (17 to 18%) Paved parking 1 (15%)

Major particulate solids sources for Washington Naval Facilities:

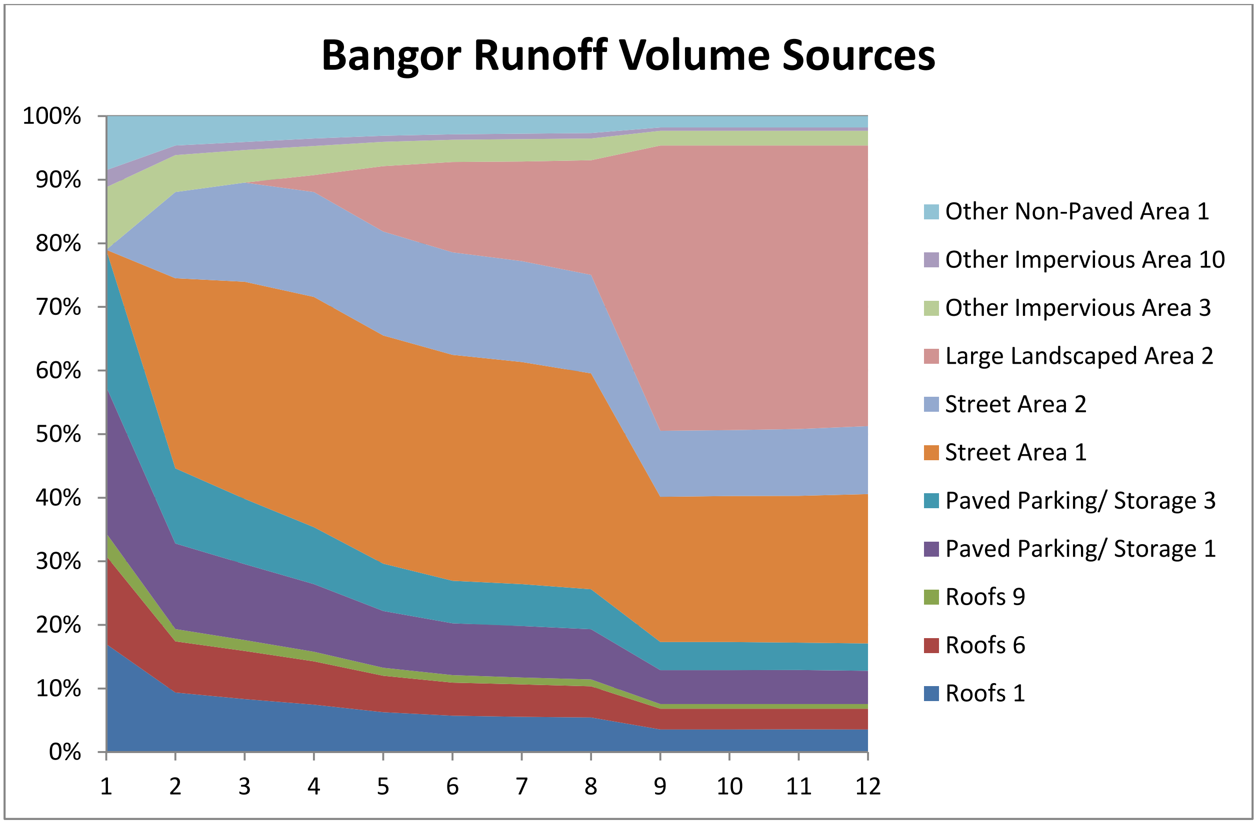
Sub area and portion of total flow	0 to 0.5 inches	0.5 to 1.5 inches	>1.5 inches
Bangor	Paved parking 1 (33 to 42%) Paved parking 3 (26 to 40%) Street 1 (0 to 17%)	Paved parking 1 (26 to 32%) Paved parking 3 (21 to 26%) Street 1 (17 to 27%)	Paved parking 1 (22 to 26%) Paved parking 3 (18 to 21%) Street 1 (27 to 32%)
Bremerton	Paved parking 1, resid. (26 to 32%) Paved parking 1 (22 to 27%) Other impervious area 4 (11 to 13%)	Paved parking 1, resid. (23 to 26%) Paved parking 1 (19 to 22%) Other impervious area 4 (10 to 11%) Street 1, resid. (8 to 13%)	Paved parking 1, resid. (18 to 23%) Paved parking 1 (15 to 19%) Street 1, resid. (13 to 14%) Large landscaped area 2, resid. (7 to 22%)
Everett	Other impervious area 3 (54 to 57%) Paved parking 1 (36 to 38%)	Other impervious area 3 (52 to 54%) Paved parking 1 (34 to 36%)	Other impervious area 3 (50 to 52%) Paved parking 1 (33 to 34%) Street 1 (9 to 13%)

Major total copper sources for Washington Naval Facilities:

Sub area and portion of total flow	0 to 0.5 inches	0.5 to 1.5 inches	>1.5 inches
Bangor	Paved parking 1 (14 to 25%) Paved parking 3 (12 to 23%) Roof 1 (9 to 15%) Roof 6 (8 to 12%) Other impervious area 3 (7 to 12%) Street 1 (0 to 24%)	Paved parking 1 (13 to 14%) Paved parking 3 (10 to 12%) Street 1 (24 to 27%) Street 2 (11 to 13%)	Street 1 (27 to 28%) Street 2 (12 to 13%) Paved parking 1 (11 to 13%) Paved parking 3 (9 to 10%) Large landscaped area 2 (3 to 10%)
Bremerton	Other impervious area 4 (35 to 39%) Paved parking 1, resid. (11 to 13%) Other impervious area 5 (10 to 11%) Paved parking 1 (9 to 10%)	Other impervious area 4 (34%) Paved parking 1, resid. (11%)	Other impervious area 4 (33%) Paved parking 1, resid. (11%)
Everett	Other impervious area 3 (69 to 75%)	Other impervious area 3 (68 to 69%)	Other impervious area 3 (67 to 68%)

Major total zinc sources for Washington Naval Facilities:

Sub area and portion of total flow	0 to 0.5 inches	0.5 to 1.5 inches	>1.5 inches
Bangor	Paved parking 1 (22 to 31%) Paved parking 3 (19 to 29%) Other impervious area 3 (11 to 16%) Street 1 (0 to 15%)	Paved parking 1 (20 to 22%) Paved parking 3 (16 to 19%) Street 1 (15 to 20%) Other impervious area 3 (10 to 11%) Other impervious area 4 (9 to 10%)	Street 1 (20 to 22%) Paved parking 1 (18 to 20%) Paved parking 3 (14 to 16%) Other impervious area 4 (9 to 10%)
Bremerton	Other impervious area 4 (21 to 25%) Paved parking 1, resid. (13 to 15%) Paved parking 1 (11 to 13%) Paved parking 1, comer. (10 to 12%)	Other impervious area 4 (21%) Paved parking 1, resid. (13%) Paved parking 1 (11%)	Other impervious area 4 (20 to 21%) Paved parking 1, resid. (12%) Paved parking 1 (10 to 11%)
Everett	Other impervious area 3 (70 to 74%) Paved parking 1 (14 to 15%)	Other impervious area 3 (69 to 70%) Paved parking 1 (14%)	Other impervious area 3 (69%) Paved parking 1 (14%)


Bangor Runoff Volume Sources
100%
90%
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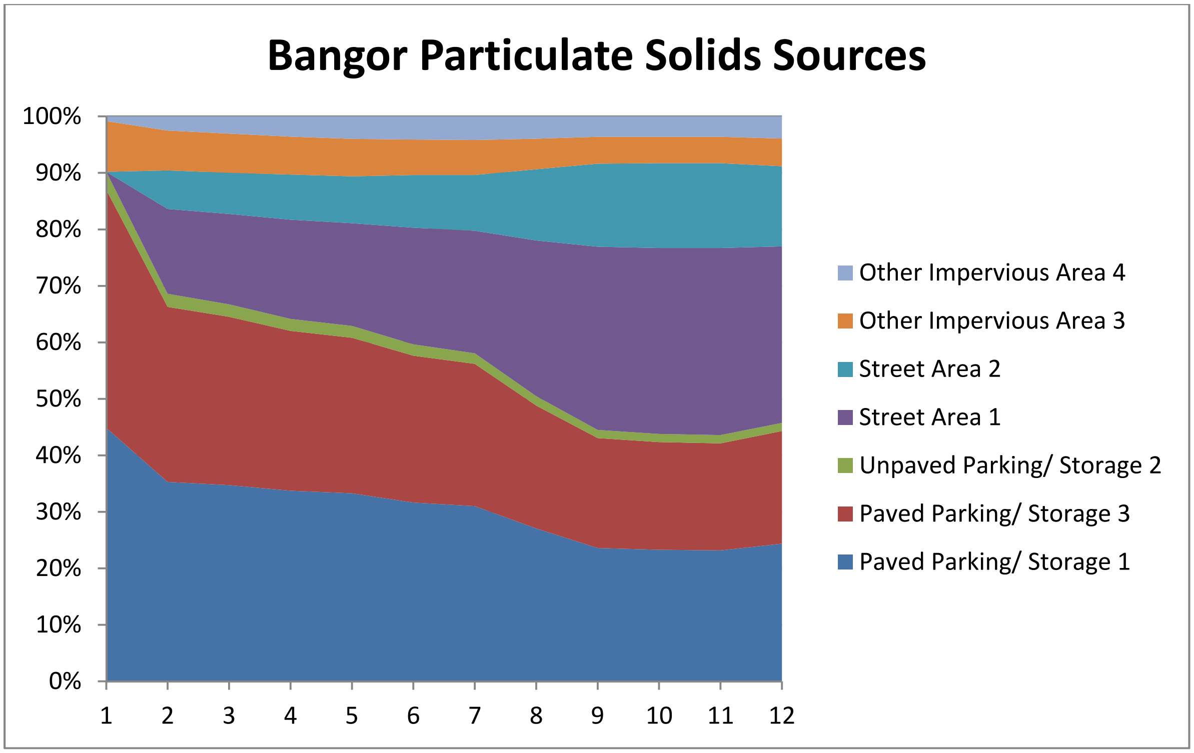
Other Non-Paved Area 1
Other Impervious Area 10
Other Impervious Area 3
Large Landscaped Area 2
Street Area 2
Street Area 1
Paved Parking/ Storage 3
Paved Parking/ Storage 1
Roofs 9
Roofs 6
Roofs 1


Bangor Particulate Solids Sources
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
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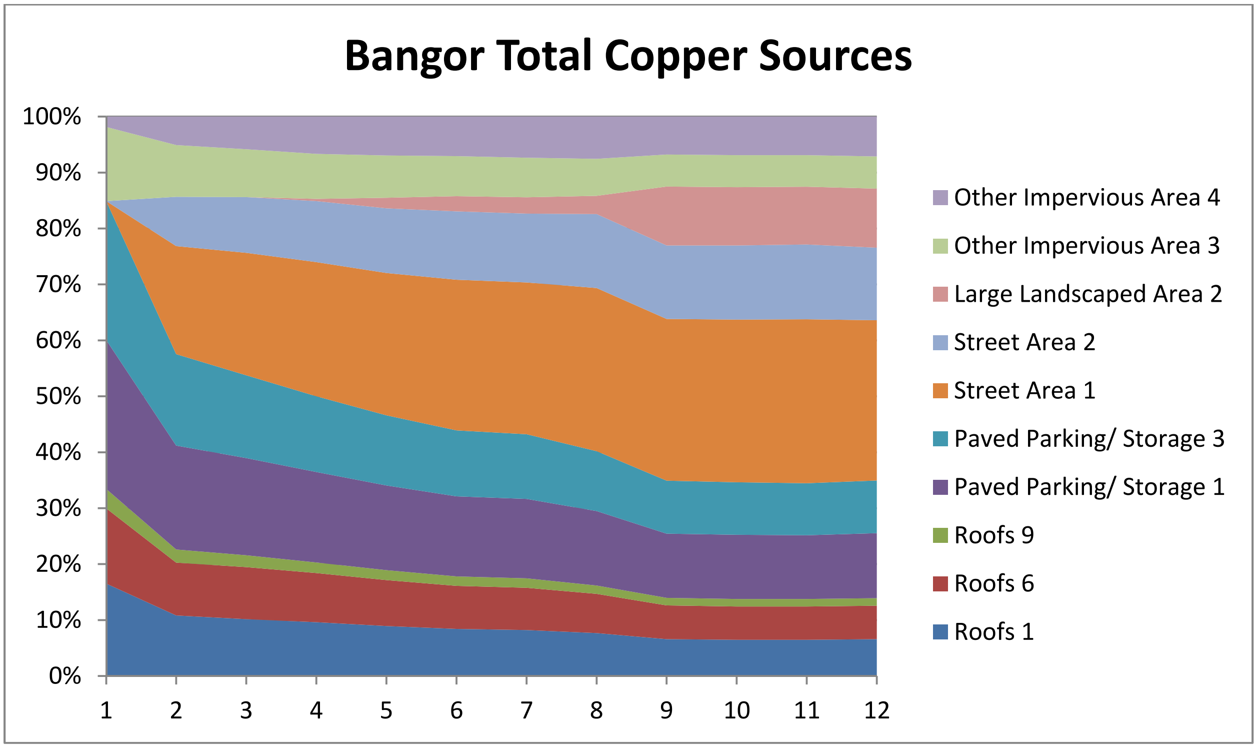
Other Impervious Area 4
Other Impervious Area 3
Street Area 2
Street Area 1
Unpaved Parking/ Storage 2
Paved Parking/ Storage 3
Paved Parking/ Storage 1


Bangor Total Copper Sources
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
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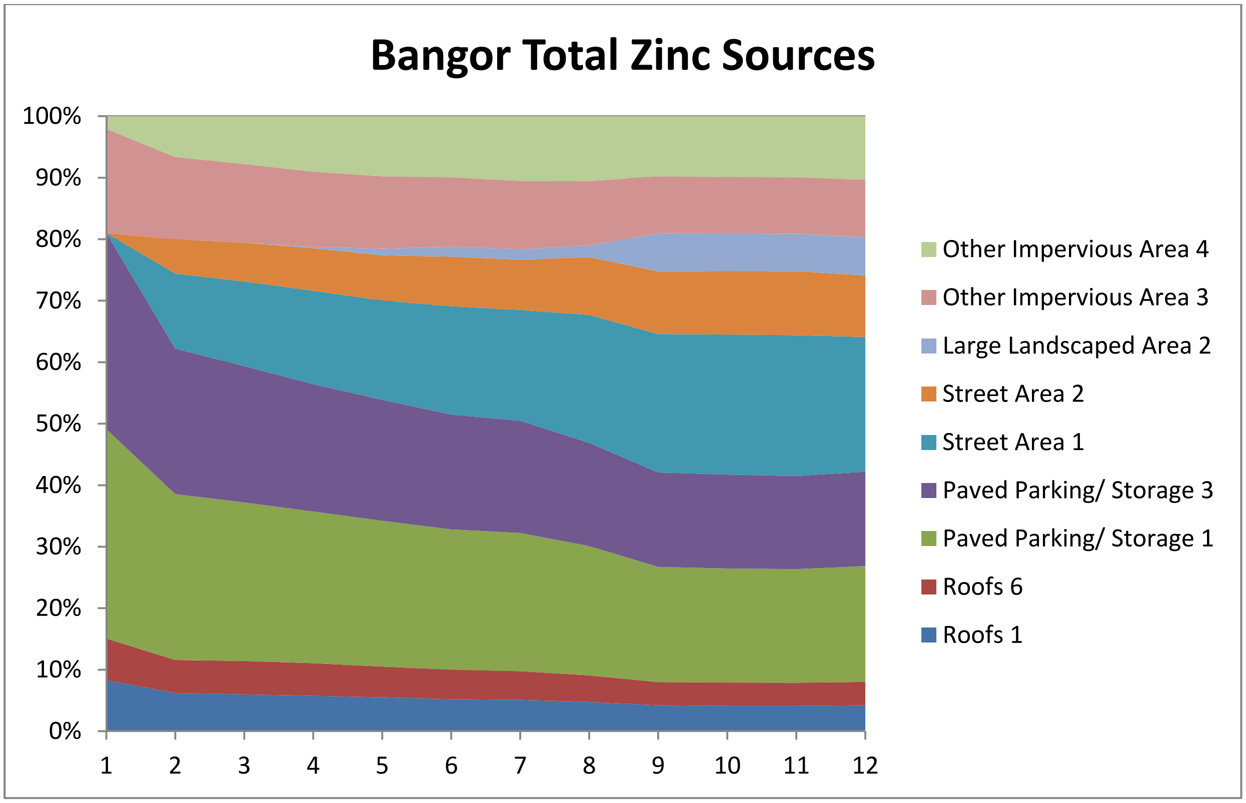
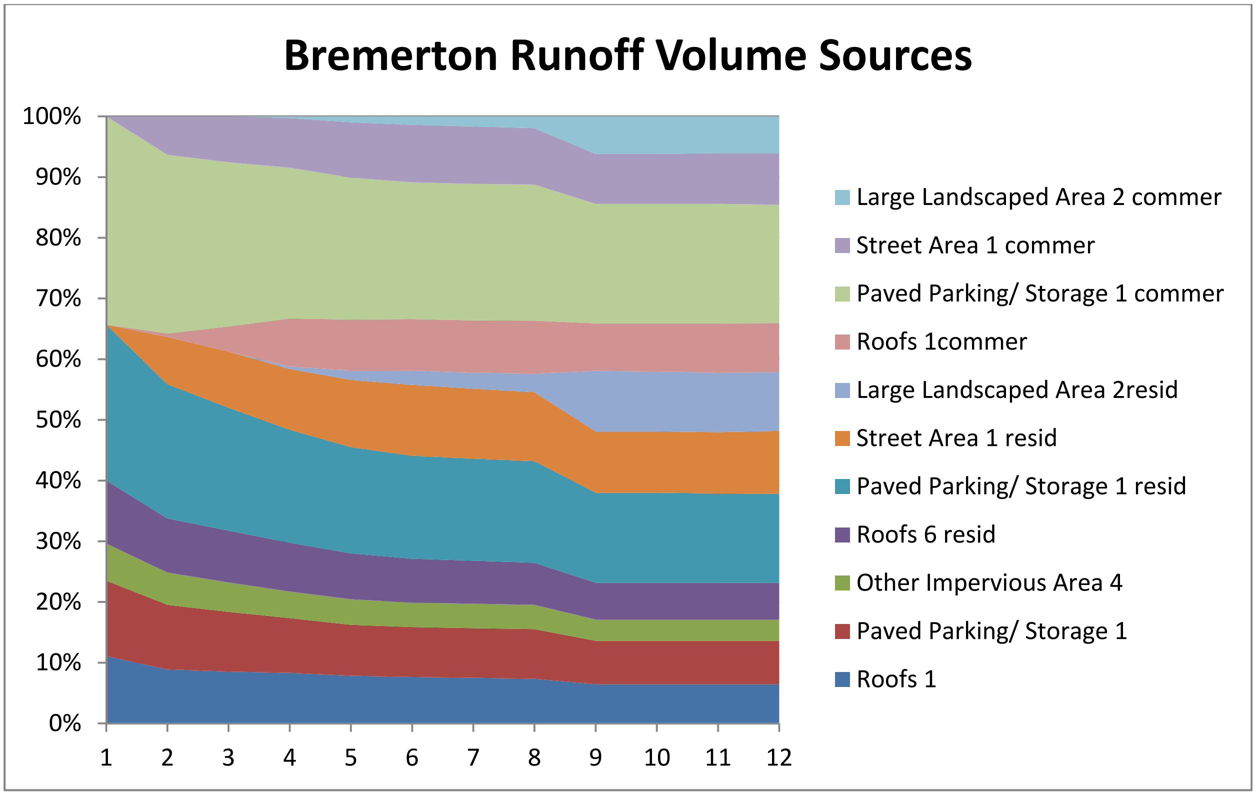
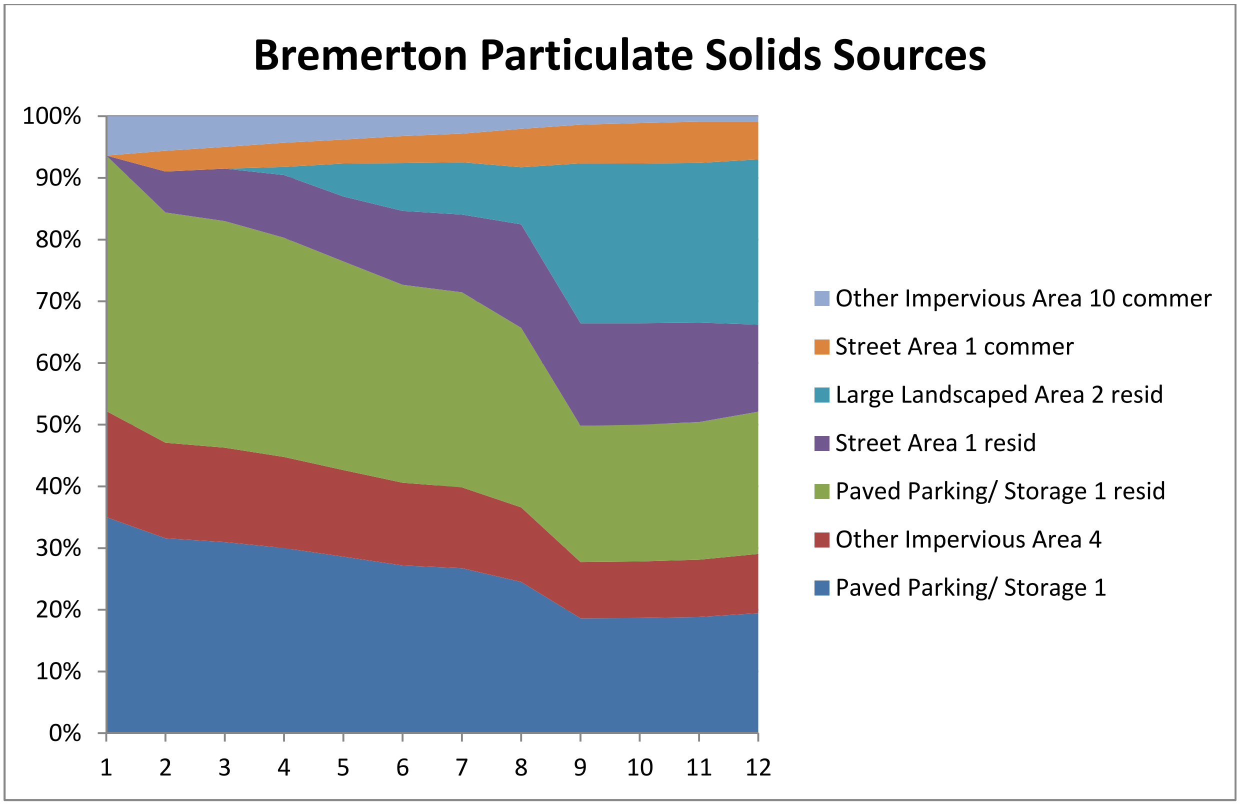
12
Other Impervious Area 4
Other Impervious Area 3
Large Landscaped Area 2
Street Area 2
Street Area 1
Paved Parking/ Storage 3
Paved Parking/ Storage 1
Roofs 9
Roofs 6
Roofs 1


Bangor Total Zinc Sources
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1
2
3
4
5
6
7
8
9
10
11
12
Other Impervious Area 4
Other Impervious Area 3
Large Landscaped Area 2
Street Area 2
Street Area 1
Paved Parking/ Storage 3
Paved Parking/ Storage 1
Roofs 6
Roofs 1


Bremerton Runoff Volume Sources
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1
2
3
4
5
6
7
8
9
10
11
12
Large Landscaped Area 2 commer
Street Area 1 commer
Paved Parking/ Storage 1 commer
Roofs 1commer
Large Landscaped Area 2resid
Street Area 1 resid
Paved Parking/ Storage 1 resid
Roofs 6 resid
Other Impervious Area 4
Paved Parking/ Storage 1
Roofs 1


Bremerton Particulate Solids Sources
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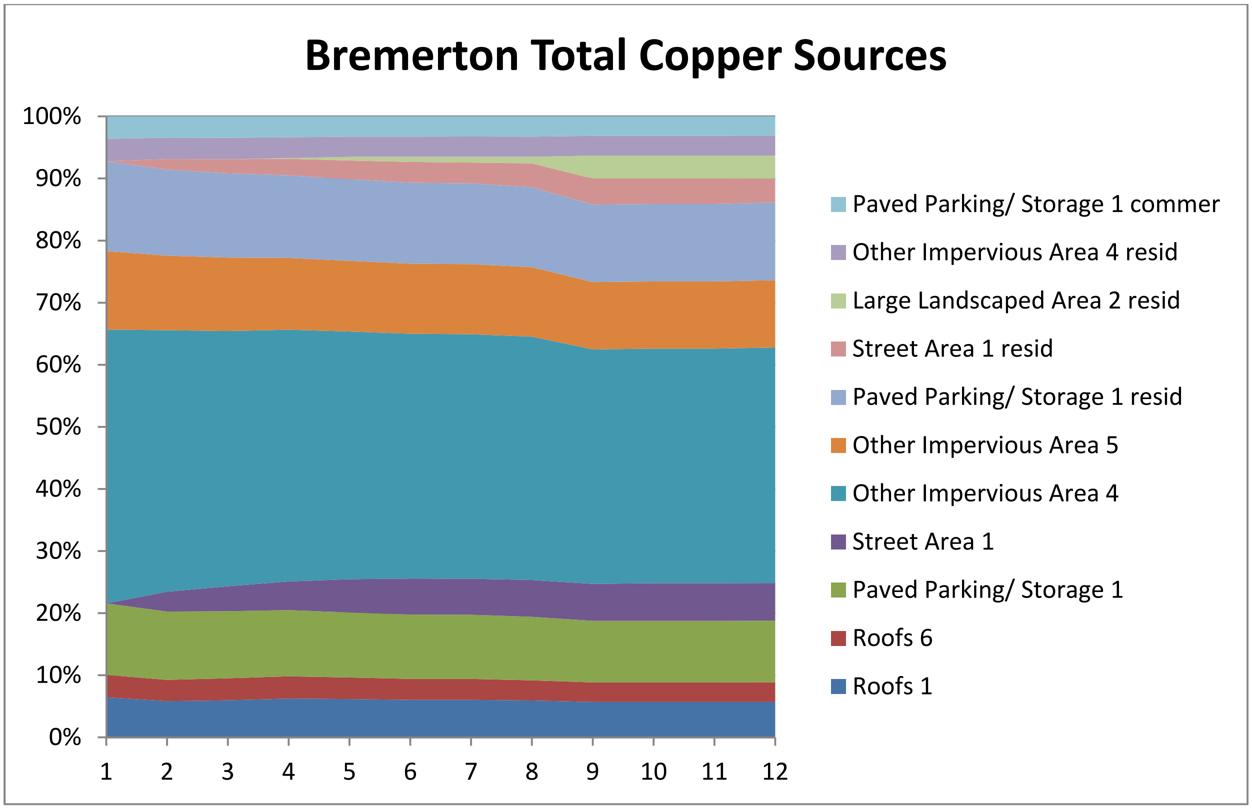
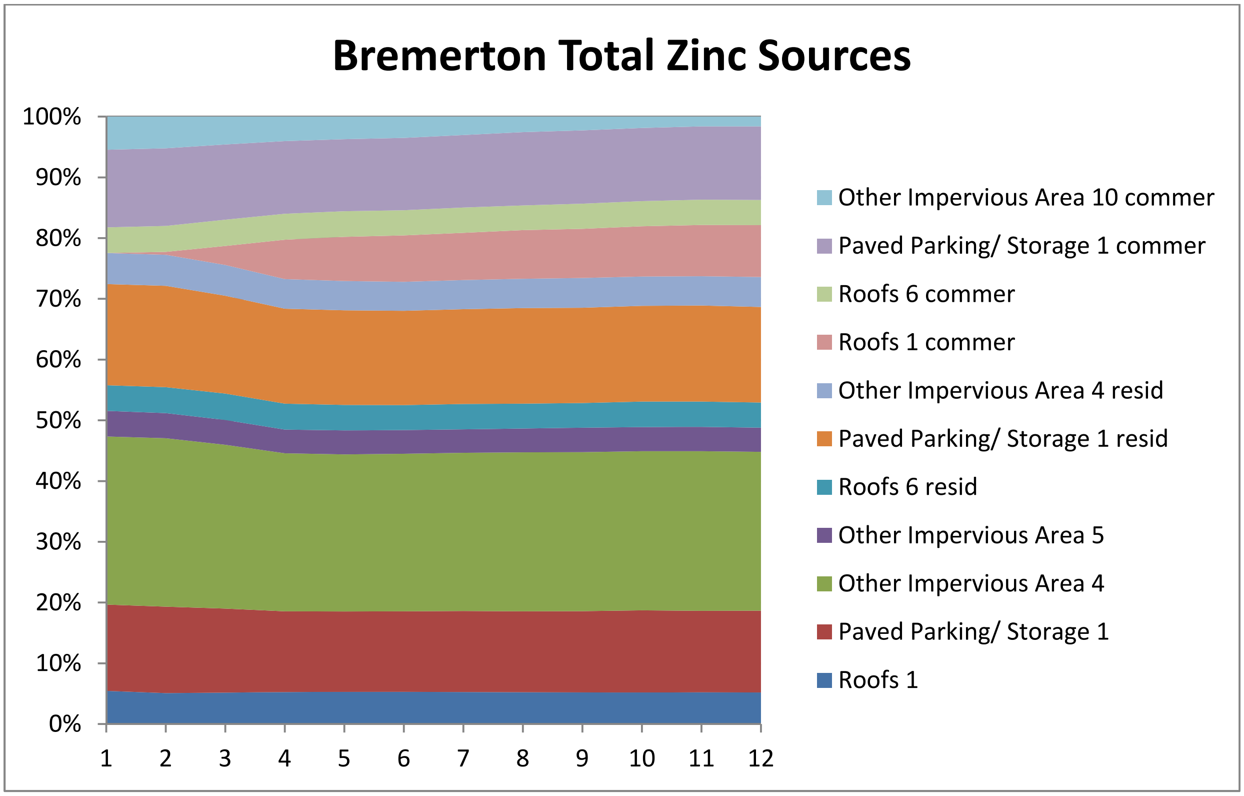
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1
2
3
4
5
6
7
8
9
10
11
12
Other Impervious Area 10 commer
Street Area 1 commer
Large Landscaped Area 2 resid
Street Area 1 resid
Paved Parking/ Storage 1 resid
Other Impervious Area 4
Paved Parking/ Storage 1


Bremerton Total Copper Sources
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1
2
3
4
5
6
7
8
9
10
11
12
Paved Parking/ Storage 1 commer
Other Impervious Area 4 resid
Large Landscaped Area 2 resid
Street Area 1 resid
Paved Parking/ Storage 1 resid
Other Impervious Area 5
Other Impervious Area 4
Street Area 1
Paved Parking/ Storage 1
Roofs 6
Roofs 1

Bremerton Total Zinc Sources
100%
90%
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40%
30%
20%
10%
0%
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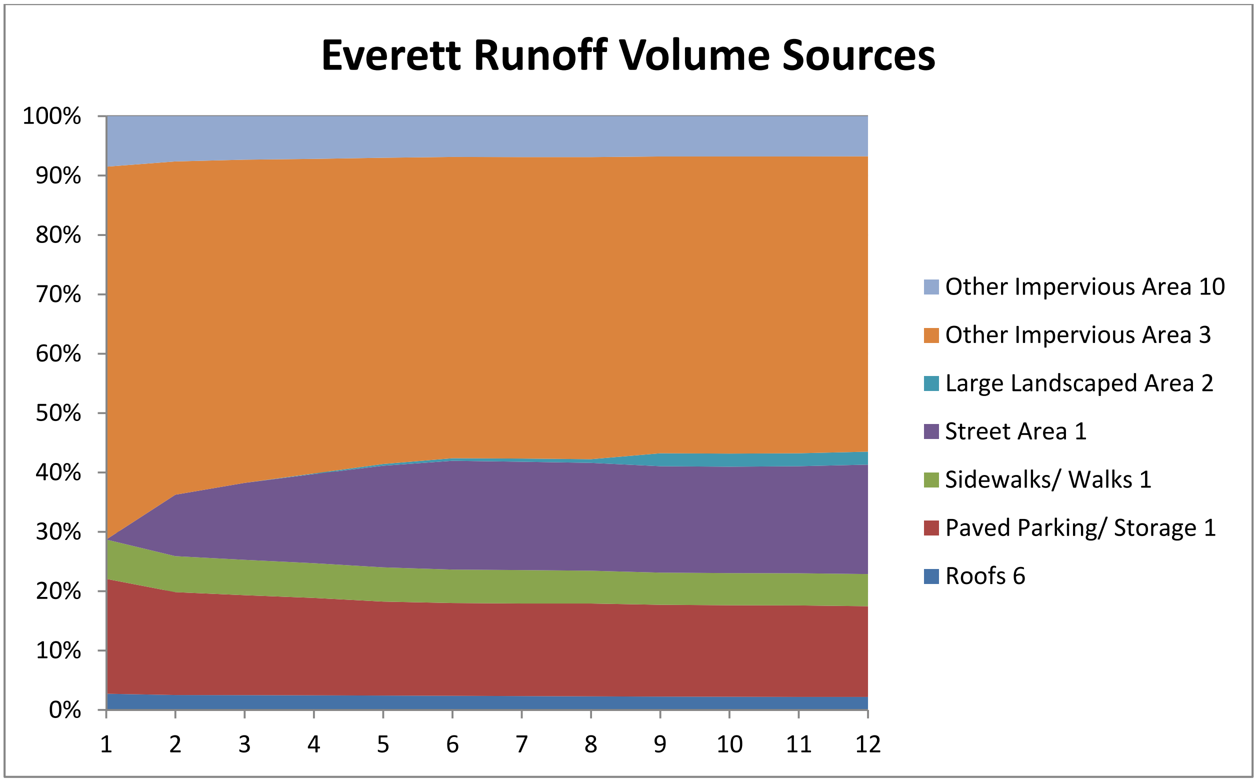
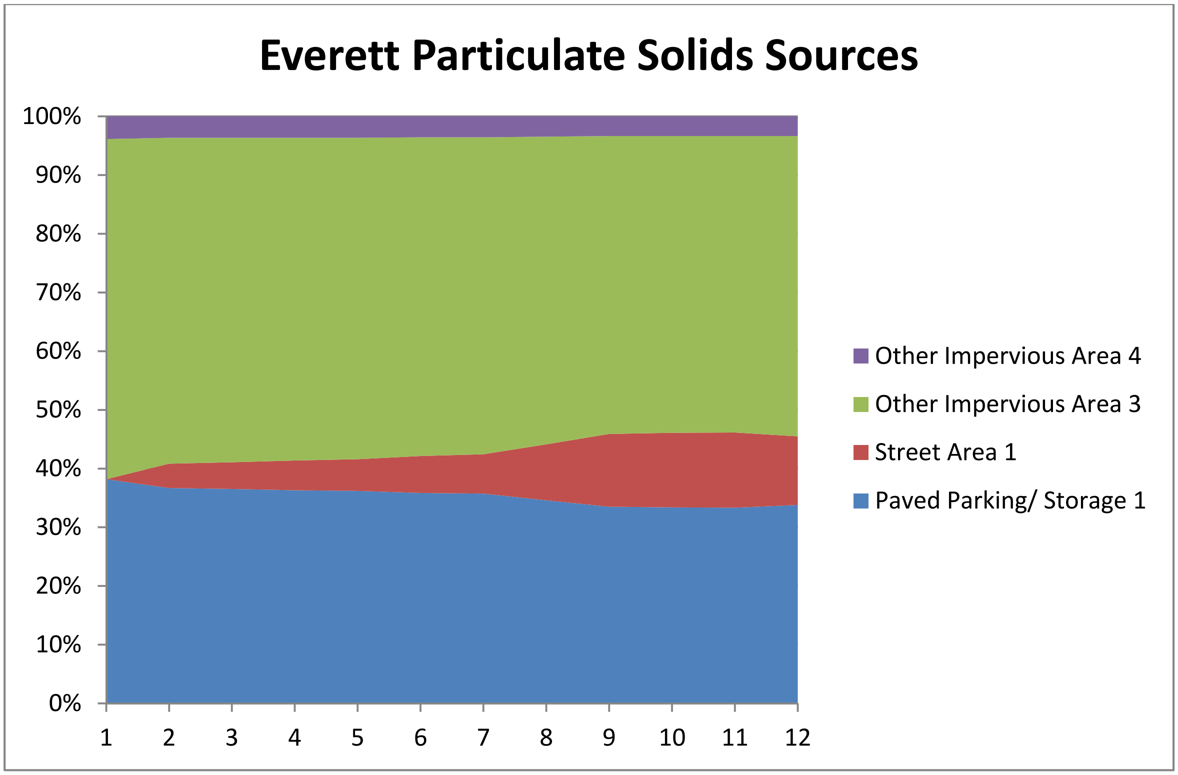
11
12
Other Impervious Area 10 commer
Paved Parking/ Storage 1 commer
Roofs 6 commer
Roofs 1 commer
Other Impervious Area 4 resid
Paved Parking/ Storage 1 resid
Roofs 6 resid
Other Impervious Area 5
Other Impervious Area 4
Paved Parking/ Storage 1
Roofs 1


Everett Runoff Volume Sources
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1
2
3
4
5
6
7
8
9
10
11
12
Other Impervious Area 10
Other Impervious Area 3
Large Landscaped Area 2
Street Area 1
Sidewalks/ Walks 1
Paved Parking/ Storage 1
Roofs 6


Everett Particulate Solids Sources
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1
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4
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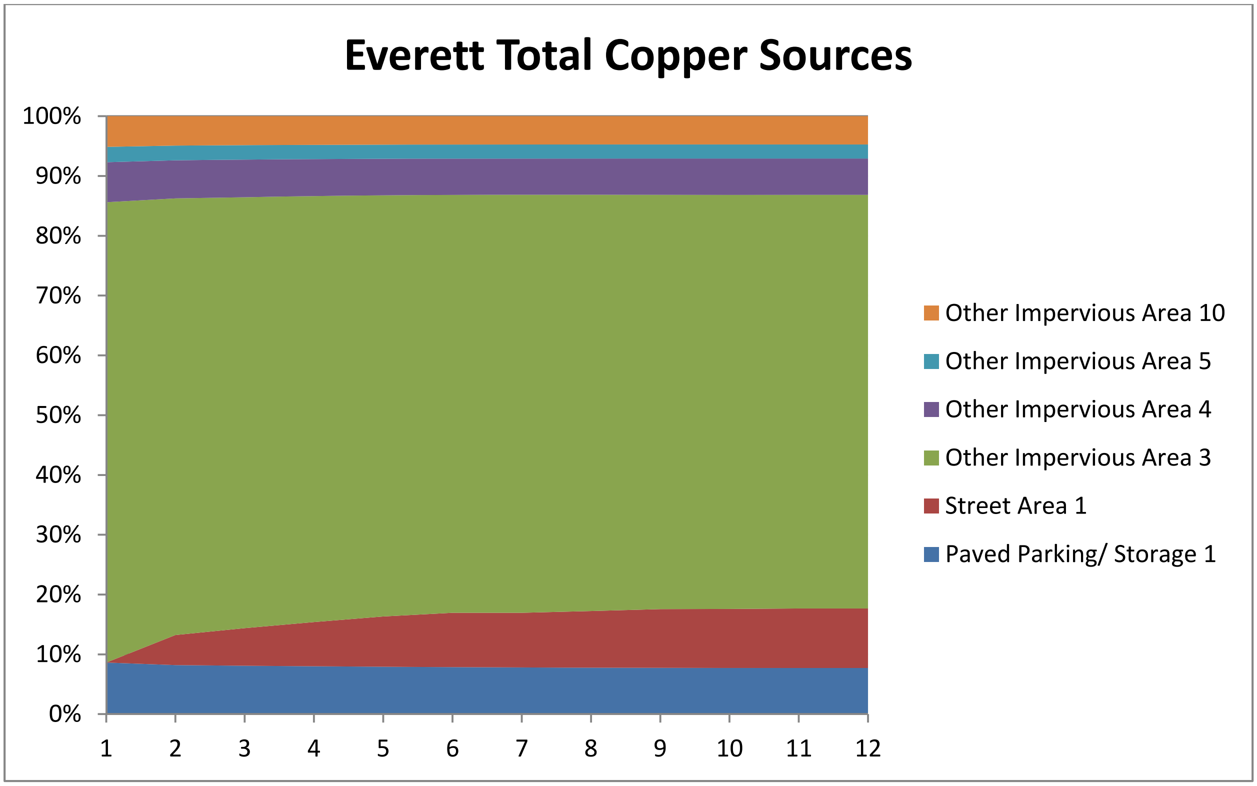
10
11
12
Other Impervious Area 4
Other Impervious Area 3
Street Area 1
Paved Parking/ Storage 1


Everett Total Copper Sources
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
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4
5
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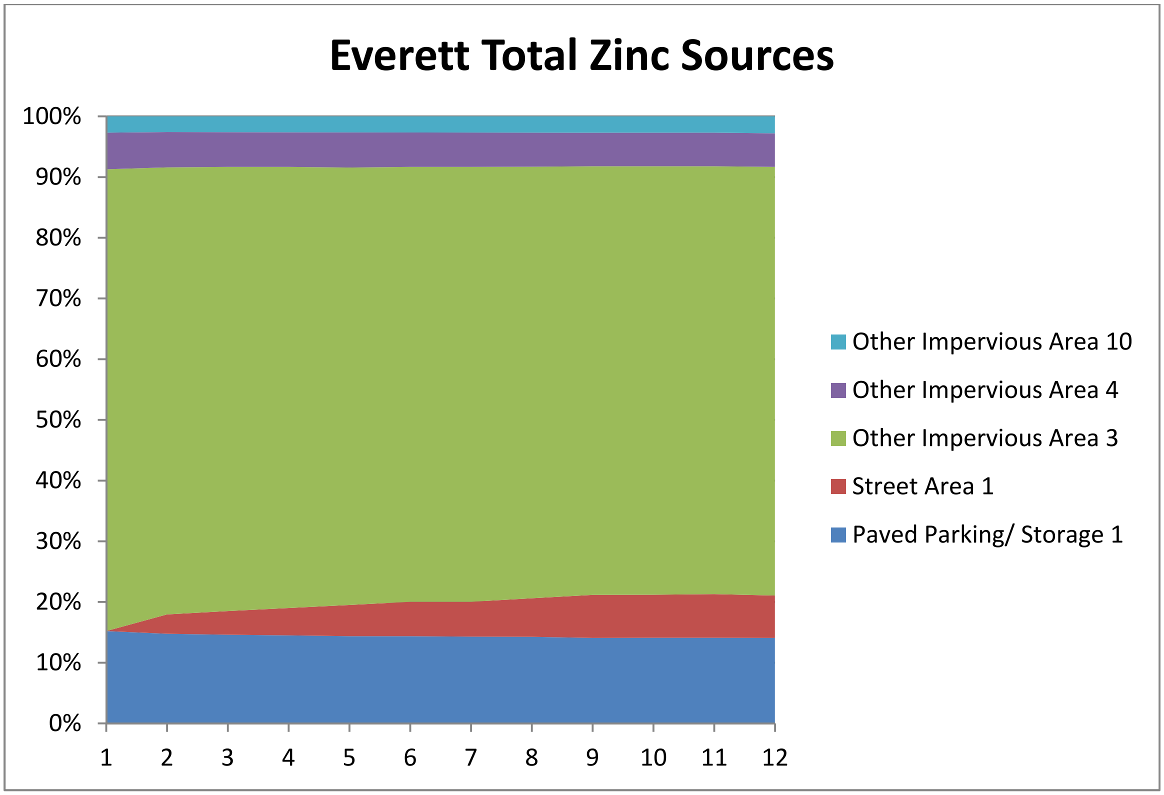
11
12
Other Impervious Area 10
Other Impervious Area 5
Other Impervious Area 4
Other Impervious Area 3
Street Area 1
Paved Parking/ Storage 1


Everett Total Zinc Sources
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1
2
3
4
5
6
7
8
9
10
11
12
Other Impervious Area 10
Other Impervious Area 4
Other Impervious Area 3
Street Area 1
Paved Parking/ Storage 1

Candidate Stormwater Controls at Naval Bases

After sources of contaminants of interest are identified, as described in the previous section, it is possible to select candidate stormwater controls that can treat the water from these identified sources. This report section briefly describes how WinSLAMM evaluates several types of stormwater controls applicable to different naval base conditions. WinSLAMM was used to examine a series of stormwater control practices, including rain barrels and water tanks for stormwater irrigation, pavement and roof disconnections, roof rain gardens, infiltration/biofiltration in parking lots and as curb-cut biofilters, grass swales, porous pavement for San Diego, Norfolk, and Puget Sound rainfall conditions. The model evaluates the practices through engineering calculations of the unit processes on the basis of the actual design and size of the controls specified, and it determines how effectively the practices remove runoff volume and pollutants.

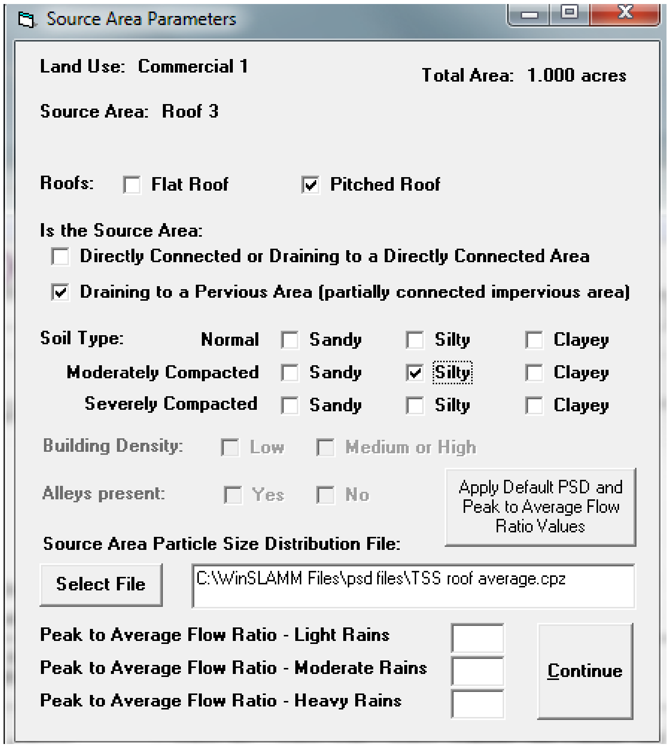
The model replicates the physical processes occurring in the stormwater control. For example, for a wet detention pond, the model incorporates the following information for each rain event:

1. Runoff hydrograph, pollution load, and sediment particle size distribution from the drainage basin to the pond
2. Pond geometry (depth, area)
3. Hydraulics of the outlet structure
4. Particle settling time and velocity in the pond based on retention time

Stokes Law and Newton's settling equations are used in conjunction with conventional surface overflow rate calculations and modified Puls-storage indication hydraulic routing methods to determine the sediment amounts and characteristics that are trapped in the pond. Again, it is important to note that the model does not apply *default* percent efficiency values to a control practice. Each rainfall is analyzed, and the pollutant control effectiveness varies according to each rainfall and the pond's antecedent condition. A full explanation of the model's capabilities, calibration, functions, and applications is at www.winslamm.com.

Pavement and Roof Disconnections

The first stormwater control that should be considered in an area is disconnecting the directly connected impervious areas, such as roofs and paved parking lots, as long as there are sufficient and suitable adjacent "pervious" areas to infiltrate the water. WinSLAMM can evaluate disconnections in different ways. The most direct way to evaluate disconnections of impervious areas is by changing the source area parameter characteristic from directly connected (or draining to a directly connected area) to draining to a pervious area (partially connected impervious area), as shown in Figure 96 for moderately compacted silty soils. If the area has normally compacted clayey soils, the building density is also needed, and if it is a medium- or high-density area, the presence of alleys also needs to be known. This process is based on extensive monitoring of residential and commercial sites that ranged from completely connected to completed disconnected with varying density and soil conditions (Pitt 1987). The following table shows the results of these disconnections, showing excellent control when all areas are disconnected. For example, to obtain good receiving water habitat conditions, all the roofs and the parking areas must be disconnected in this example. As expected from observing the flow source area plot, disconnecting only a portion of these impervious areas has limited benefits. It is noted that the concentrations of the pollutants increase with increasing roof disconnections because the better quality roof runoff is being infiltrated and not diluting the runoff from the paved parking/storage area. However, the mass discharges all decrease with increased disconnections.



Land Use: Commercial 1

Total Area: 1.000 acres

Source Area: Roof 3

Roofs: ☐ Flat Roof ☑ Pitched Roof

Is the Source Area:
☐ Directly Connected or Draining to a Directly Connected Area
☑ Draining to a Pervious Area (partially connected impervious area)

Soil Type:
Normal ☐ Sandy ☐ Silty ☐ Clayey
Moderately Compacted ☐ Sandy ☑ Silty ☐ Clayey
Severely Compacted ☐ Sandy ☐ Silty ☐ Clayey

Building Density: ☐ Low ☐ Medium or High

Alleys present: ☐ Yes ☐ No

Source Area Particle Size Distribution File: C:\WinSLAMM Files\psd files\TSS roof average.cpz

Peak to Average Flow Ratio - Light Rains
Peak to Average Flow Ratio - Moderate Rains
Peak to Average Flow Ratio - Heavy Rains

Disconnection of pitched roof to silty soil

The most important consideration is the amount and quality of the non-paved area that would receive the runoff from the paved or roof area. A later discussion presents information for grass filters (that considers both infiltration and particulate retention benefits) that can be most suitably used for the large areas on naval bases. Many of the San Diego base non-paved areas are covered with artificial turf and would not likely be a suitable area to drain excess water.

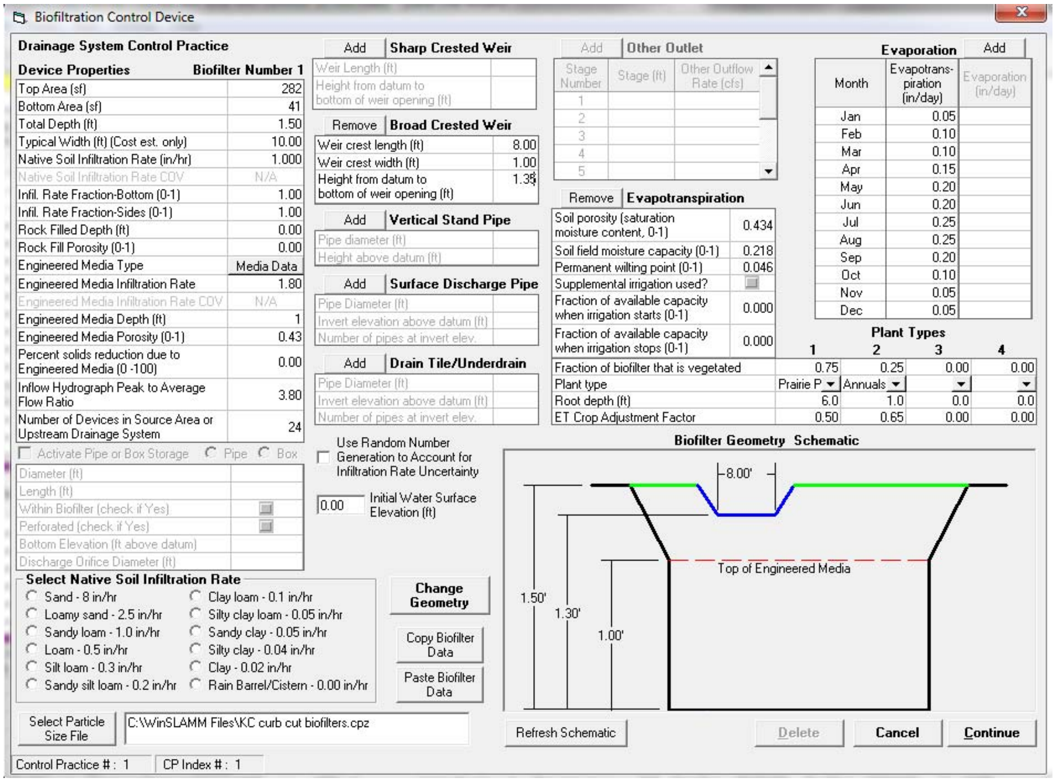
The benefits of disconnecting connected paved parking or storage areas are similar to the benefits for disconnecting roofs. However, disconnecting these areas as part of a retrofit program is likely to be difficult because extensive re-grading would be needed, or at least a suitable adjacent undeveloped or landscaped area downgradient of the paved area would be needed. The use of biofilters to infiltrate the runoff at directly connected paved areas is likely a much more suitable option, especially for retrofits.

Roof Runoff Rain Gardens

The performance of rain gardens is affected by several unit processes which are modeled in WinSLAMM. Modified puls hydraulic routing, with surface overflow calculations, are the basic processes used. However, several layers in the rain garden (or biofilter) must be considered. As runoff enters the device, water infiltrates through the engineered soil or media (or natural soil, in a rain garden). If the entering rain cannot all be infiltrated through the surface layer, the water ponds. If the ponding becomes deep, it can overflow through the surface outlet. The percolating water moves down through the device until it reaches the bottom and intercepts the native soil. If the native soil infiltration rate is greater than the percolation water rate, no subsurface ponding occurs; if the native soil infiltration rate is slower than the percolation water rate, subsurface ponding occurs. This ponding can build up to the surface of the device and add to the surface ponding. If an underdrain is present (usually with a subsurface storage layer), the subsurface ponding will be intercepted by the drain which then discharges it to the surface water, but hopefully later in the event when the effects are moderated.

With the water percolating through the engineered soil or other fill, particulates and particulate-bound pollutants are trapped by the media through filtering actions. Therefore, the underdrain water usually has a lower particulate solids content that the surface waters entering the device, except if fines are washed from the media. The calculations are sensitive to the amount of the different media materials used as fill (or the native soil) and its characteristics (especially its porosity and percolation rate; the amount of fines, and if ET is considered, the wilting point). The hydraulic routing uses the sum of the void volumes in the device to determine the effluent hydrograph, while the different infiltration/percolation rates affect the internal ponding. The stage-discharge relationships of the outlet devices are all modeled using conventional hydraulic processes. The ET loss calculations are based on the changing water content in the root zone at each time increment, and the ET adjustment factors for the mixture of plants in the device (Pitt, *et al.* 2008a).

The following figure is the main WinSLAMM input screen used for rain gardens. This is a general form that is also used for other infiltration devices, including biofilters and bioinfiltration devices (and even green roofs until that special form is completed in a future model version). This form includes the geometry of the device and material placed in the device. Most simple rain gardens do not have any special media, using only soils, nor do they have underdrains, so only some of the form is used. In this example, a loam soil is used in the rain garden, and the subsurface native soil is assumed to be a sandy loam having long-term infiltration rates of about 1.0 in/hr. As indicated, it is possible to also incorporate a Monte Carlo routine to better represent the variable infiltration rates that any individual unit has. All the devices using this input screen require a hydraulic overflow outlet described as a broad crested weir. For these infiltration devices, evaporation of water from any pooled standing water above the soil and ET losses associated with plants installed in the rain garden, are also added as outlet devices. The engineered soil media characteristics screen is shown in a following figure, as an example.



Drainage System Control Practice

Device Properties	Biofilter Number 1
Top Area (sf)	282
Bottom Area (sf)	41
Total Depth (ft)	1.50
Typical Width (ft) (Cost est. only)	10.00
Native Soil Infiltration Rate (in/hr)	1.000
Native Soil Infiltration Rate COV	N/A
Infil. Rate Fraction-Bottom (0-1)	1.00
Infil. Rate Fraction-Sides (0-1)	1.00
Rock Filled Depth (ft)	0.00
Rock Fill Porosity (0-1)	0.00
Engineered Media Type	Media Data
Engineered Media Infiltration Rate	1.80
Engineered Media Infiltration Rate COV	N/A
Engineered Media Depth (ft)	1
Engineered Media Porosity (0-1)	0.43
Percent solids reduction due to Engineered Media (0 -100)	0.00
Inflow Hydrograph Peak to Average Flow Ratio	3.80
Number of Devices in Source Area or Upstream Drainage System	24

☐ Activate Pipe or Box Storage ○ Pipe ○ Box

Diameter (ft)	
Length (ft)	
Within Biofilter (check if Yes)	☐
Perforated (check if Yes)	☐
Bottom Elevation (ft above datum)	
Discharge Orifice Diameter (ft)	

Sharp Crested Weir

Weir Length (ft)	
Height from datum to bottom of weir opening (ft)	

Broad Crested Weir

Weir crest length (ft)	8.00
Weir crest width (ft)	1.00
Height from datum to bottom of weir opening (ft)	1.35

Vertical Stand Pipe

Pipe diameter (ft)	
Height above datum (ft)	

Surface Discharge Pipe

Pipe Diameter (ft)	
Invert elevation above datum (ft)	
Number of pipes at invert elev.	

Drain Tile/Underdrain

Pipe Diameter (ft)	
Invert elevation above datum (ft)	
Number of pipes at invert elev.	

☐ Use Random Number Generation to Account for Infiltration Rate Uncertainty

0.00 Initial Water Surface Elevation (ft)

Other Outlet

Stage Number	Stage (ft)	Other Outflow Rate (cfs)
1		
2		
3		
4		
5		

Evapotranspiration

Soil porosity (saturation moisture content, 0-1)	0.434
Soil field moisture capacity (0-1)	0.218
Permanent wilting point (0-1)	0.046
Supplemental irrigation used?	☐
Fraction of available capacity when irrigation starts (0-1)	0.000
Fraction of available capacity when irrigation stops (0-1)	0.000

Evaporation

Month	Evapotranspiration (in/day)	Evaporation (in/day)
Jan	0.05	
Feb	0.10	
Mar	0.10	
Apr	0.15	
May	0.20	
Jun	0.20	
Jul	0.25	
Aug	0.25	
Sep	0.20	
Oct	0.10	
Nov	0.05	
Dec	0.05	

Plant Types

	1	2	3	4
Fraction of biofilter that is vegetated	0.75	0.25	0.00	0.00
Plant type	Prairie P	Annuals		
Root depth (ft)	6.0	1.0	0.0	0.0
ET Crop Adjustment Factor	0.50	0.65	0.00	0.00

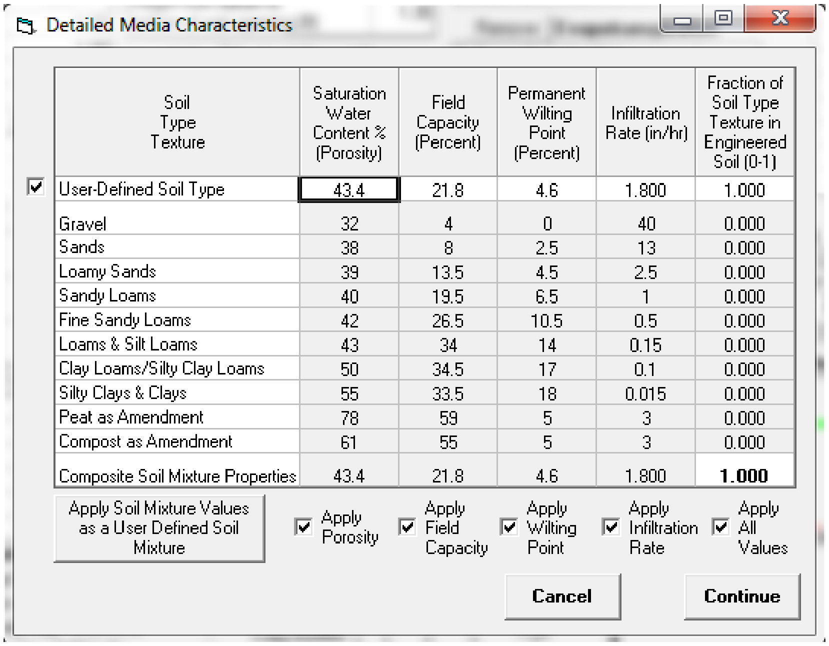
Select Native Soil Infiltration Rate

- ○ Sand - 8 in/hr
- ○ Loamy sand - 2.5 in/hr
- ○ Sandy loam - 1.0 in/hr
- ○ Loam - 0.5 in/hr
- ○ Silt loam - 0.3 in/hr
- ○ Sandy silt loam - 0.2 in/hr
- ○ Clay loam - 0.1 in/hr
- ○ Silty clay loam - 0.05 in/hr
- ○ Sandy clay - 0.05 in/hr
- ○ Silty clay - 0.04 in/hr
- ○ Clay - 0.02 in/hr
- ○ Rain Barrel/Cistern - 0.00 in/hr

C:\WinSLAMM Files\KC curb cut biofilters.cpz

Control Practice # : 1 CP Index # : 1

Rain garden input screen.



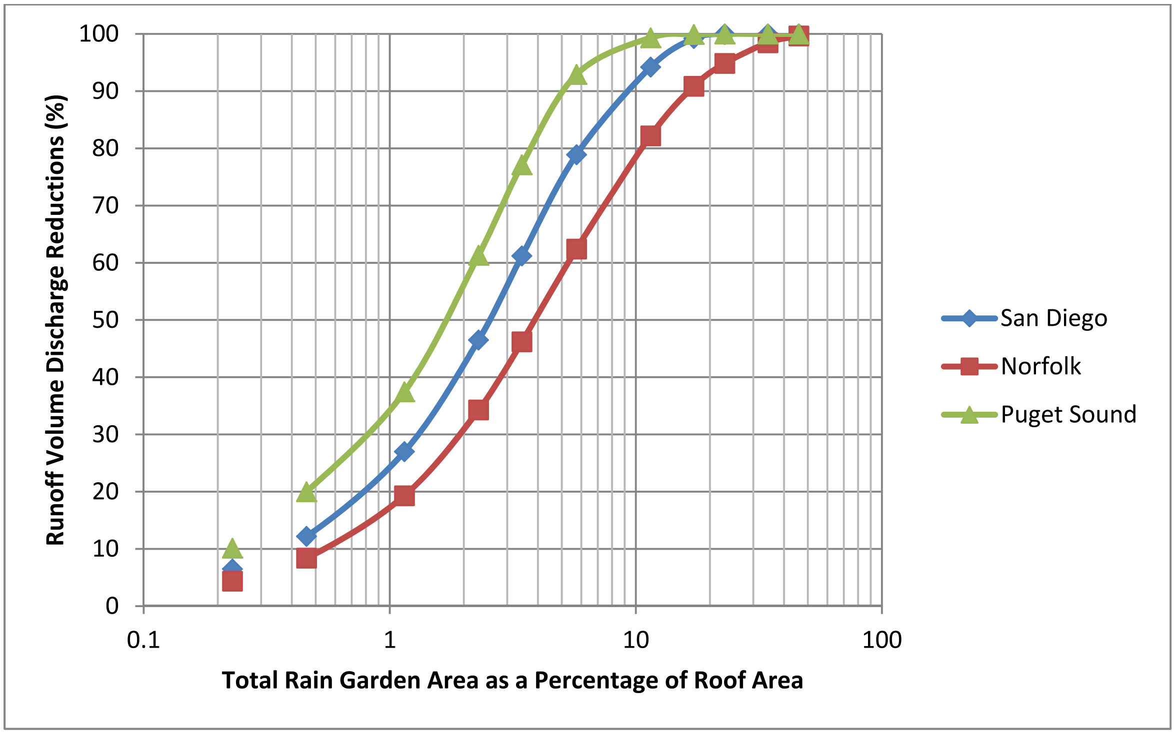
	Soil Type Texture	Saturation Water Content % (Porosity)	Field Capacity (Percent)	Permanent Wilting Point (Percent)	Infiltration Rate (in/hr)	Fraction of Soil Type Texture in Engineered Soil (0-1)
☑	User-Defined Soil Type	43.4	21.8	4.6	1.800	1.000
	Gravel	32	4	0	40	0.000
	Sands	38	8	2.5	13	0.000
	Loamy Sands	39	13.5	4.5	2.5	0.000
	Sandy Loams	40	19.5	6.5	1	0.000
	Fine Sandy Loams	42	26.5	10.5	0.5	0.000
	Loams & Silt Loams	43	34	14	0.15	0.000
	Clay Loams/Silty Clay Loams	50	34.5	17	0.1	0.000
	Silty Clays & Clays	55	33.5	18	0.015	0.000
	Peat as Amendment	78	59	5	3	0.000
	Compost as Amendment	61	55	5	3	0.000
	Composite Soil Mixture Properties	43.4	21.8	4.6	1.800	**1.000**

Apply Soil Mixture Values as a User Defined Soil Mixture

☑ Apply Porosity ☑ Apply Field Capacity ☑ Apply Wilting Point ☑ Apply Infiltration Rate ☑ Apply All Values

Detailed media characteristics for rain gardens.

The performance of a rain garden for controlling runoff from directly connected flat roofs is summarized in the following figure. The rain garden modeled has 100ft^2 of surface area and 50ft^2 of bottom area and in 1 ft deep. There was no material added to the bottom of the rain garden, nor is there an underdrain used (these are usually defining features of biofilters, discussed later). The soil is a loam having a 0.5 in/hr infiltration rate. A broad-crested weir is used as the surface overflow, providing 9 inches of ponding for water storage in the excavation. The model was run using various numbers of these rain gardens for a total one acre of flat roofs. The results were normalized in the following graph by expressing the total rain garden surface area as a percentage of the roof area. Long-term continuous rains were evaluated for these different sized rain gardens: San Diego 2000 to 2006; Norfolk 2000 to 2013; and Puget Sound (Everett rains) 2000 to 2009. As expected, as the total rain garden increases in size in relationship to the roof area, less water is discharged to the surface drainage system through the overflow. As noted, the rain garden has no underdrain, so the pollutant reductions are the same as for the runoff volume reductions. The same sized rain gardens are most effective for the Puget Sound area, then San Diego, and then Norfolk. This ranking is mostly dependent on the amount of rainfall and its intensity. The Puget Sound area has similar rain totals as Norfolk, but the rain intensities (and therefore runoff rates) are much less, allowing the water to be more effectively infiltrated. In order to capture about 90% of the long-term rainfall amount, the total rain gardens in Puget Sound would need to be about 5% of the roof area, increasing to 9% for San Diego, and further increasing to about 15% for Norfolk. As discussed later, the use of biofilters typically results in much smaller footprint areas for the same level of control, but at higher construction costs.



Calculated rain garden performance at San Diego, Norfolk, and Puget Sound naval bases.

Biofilters

Biofilters are excavations to collect runoff and allow infiltration. They are usually filled with a rock storage layer, and treatment layer, and most have underdrains to prevent excessive ponding for extended times. Because of the increased amount of storage compared to a simple rain garden, biofilters can better handle short periods of increased runoff and larger amounts of runoff.

Biofilter performance is based on the characteristics of the flow entering the device, the infiltration rate into the native soil, the filtering capacity and infiltration rate of the engineered media fill if used, the amount of rock fill storage, the size of the device and the outlet structures for the device. Pollutant filtering by the engineered media (usually containing amendments) is based on the engineered media type and the particle size distribution of the particulates in the inflowing water. If the engineered media flow rate is lower than the flow rates entering the device, the engineered media will affect the device performance by forcing the excess water to bypass the device through surface discharges, if the storage capacity above the engineered media is inadequate.

The device operation is modeled using the Modified Puls Storage-Indication method and is analyzed differently depending on whether a rock and engineered media layer is in the model. The model simulates the inflow and outflow hydrographs using a time interval selected by the user (typically 6 minutes), although this interval is reduced automatically by the program if the simulation calculations approach becoming unstable.

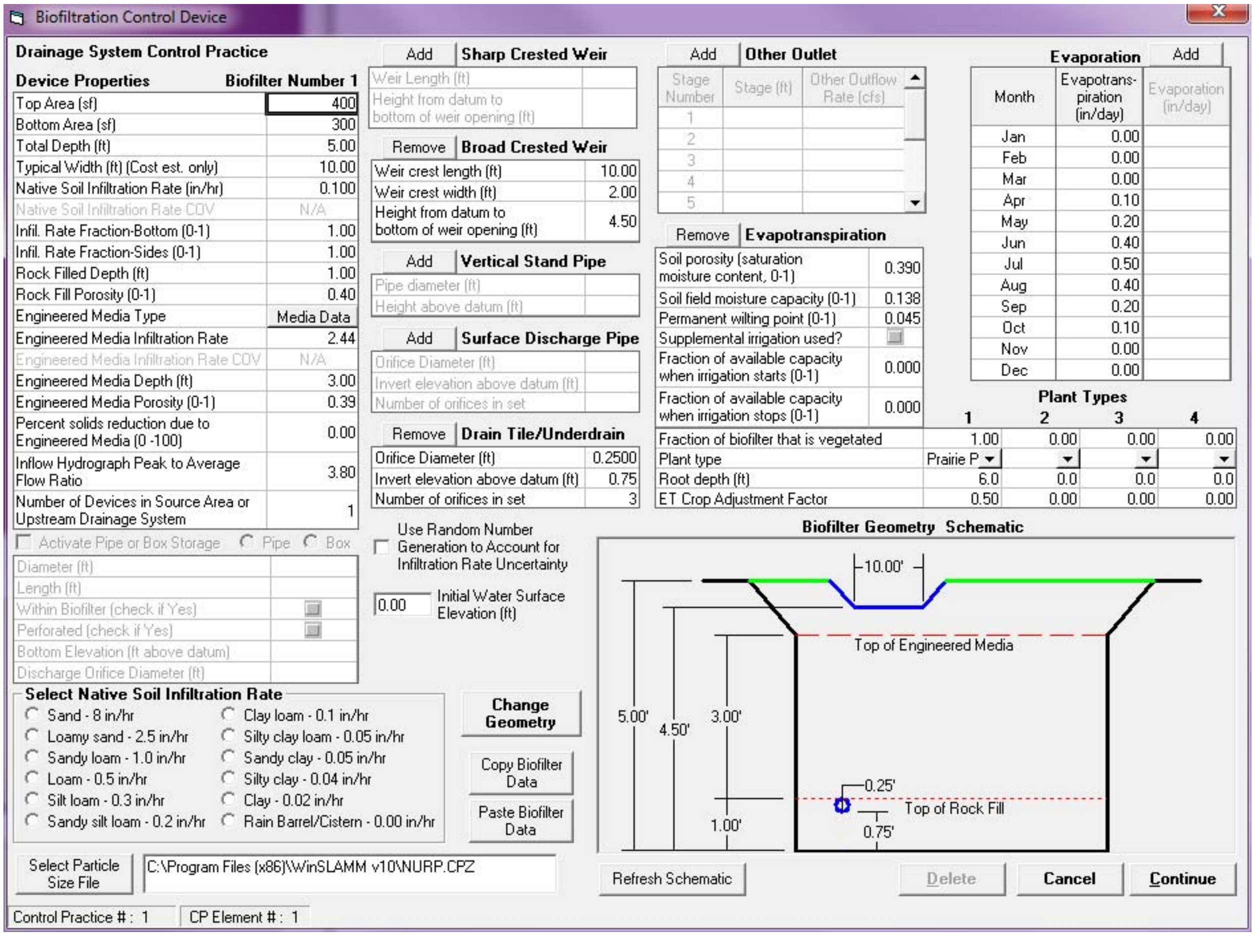
The inflow hydrograph is divided into the selected time intervals, which are routed to the surface of the biofilter. The biofilter is evaluated in two basic sections: the aboveground section (or above the engineered media) and the belowground section (below the surface of the engineered media). If there is a rock layer and an engineered media layer, separate details are entered for each. The available surface outflow devices include broad crested weirs (required to have at least one as the surface overflow outlet), and optional crested weirs, vertical stand pipes, and evaporation/ET. An underdrain is also optional that discharges back to the drainage system (but with “filtered” water).

As water enters the device, the flow only enters the belowground section if the engineered media infiltration rate is greater than the inflowing water rate. If the inflow rate increases to be greater than the media infiltration rate, the aboveground storage begins to fill. If the inflowing rate is high enough and the excess runoff volume exceeds the available storage, the water discharges from the device through the aboveground surface broad crested weir outflow, and any other surface outlet. As water enters the belowground section of the device, it passes through the native media and, as the bottom section fills, it may enter an underdrain (if used). All water that flows through the underdrain is assumed to be filtered by the engineered media. The filtering performance changes based on the type of engineered media and varies by the particle size of the particulates in the water. If the water level in the belowground section of the device reaches the top of the engineered media layer, infiltration from the surface layer into the belowground layer stops until the water level in the belowground section is below the top of the engineered media layer. If there are no rock and engineered media layers, flow into the native soil is considered to be an outflow: there is no belowground section, and all treatment by the device is assumed to be through volume loss by infiltration into the native soil (this is the typical way rain gardens operate, since they have no media or underdrain, but do have surface storage).

To model biofilters, the geometry and other characteristics of the biofilter are described, or of a typical biofilter if modeling a set of biofilters for, say, roofs or parking lot source areas. The number of biofilters to be modeled in the source area is also entered on the form. The model divides the total source area runoff volume by the number of biofilters in the source area, creates a complex triangular hydrograph for that representative flow fraction that is then routed through that biofilter. It then multiplies the resulting runoff pollutant and flow reductions by the number of biofilters for the total source area effects.

Biofilter Data Entry

The following figure is the data entry form used for biofilters and related stormwater controls.



Biofiltration Control Device

Drainage System Control Practice

Device Properties	Biofilter Number 1
Top Area (sf)	400
Bottom Area (sf)	300
Total Depth (ft)	5.00
Typical Width (ft) (Cost est. only)	10.00
Native Soil Infiltration Rate (in/hr)	0.100
Native Soil Infiltration Rate COV	N/A
Infil. Rate Fraction-Bottom (0-1)	1.00
Infil. Rate Fraction-Sides (0-1)	1.00
Rock Filled Depth (ft)	1.00
Rock Fill Porosity (0-1)	0.40
Engineered Media Type	Media Data
Engineered Media Infiltration Rate	2.44
Engineered Media Infiltration Rate COV	N/A
Engineered Media Depth (ft)	3.00
Engineered Media Porosity (0-1)	0.39
Percent solids reduction due to Engineered Media (0 -100)	0.00
Inflow Hydrograph Peak to Average Flow Ratio	3.80
Number of Devices in Source Area or Upstream Drainage System	1

☐ Activate Pipe or Box Storage ○ Pipe ○ Box

Diameter (ft)	
Length (ft)	
Within Biofilter (check if Yes)	☐
Perforated (check if Yes)	☐
Bottom Elevation (ft above datum)	
Discharge Orifice Diameter (ft)	

Select Native Soil Infiltration Rate

○ Sand - 8 in/hr
○ Loamy sand - 2.5 in/hr
○ Sandy loam - 1.0 in/hr
○ Loam - 0.5 in/hr
○ Silt loam - 0.3 in/hr
○ Sandy silt loam - 0.2 in/hr
○ Clay loam - 0.1 in/hr
○ Silty clay loam - 0.05 in/hr
○ Sandy clay - 0.05 in/hr
○ Silty clay - 0.04 in/hr
○ Clay - 0.02 in/hr
○ Rain Barrel/Cistern - 0.00 in/hr

Select Particle Size File: C:\Program Files (x86)\WinSLAMM v10\NURP.CPZ

Control Practice # : 1 CP Element # : 1

Sharp Crested Weir (Add)

Weir Length (ft)	
Height from datum to bottom of weir opening (ft)	

Broad Crested Weir (Remove)

Weir crest length (ft)	10.00
Weir crest width (ft)	2.00
Height from datum to bottom of weir opening (ft)	4.50

Vertical Stand Pipe (Add)

Pipe diameter (ft)	
Height above datum (ft)	

Surface Discharge Pipe (Add)

Orifice Diameter (ft)	
Invert elevation above datum (ft)	
Number of orifices in set	

Drain Tile/Underdrain (Remove)

Orifice Diameter (ft)	0.2500
Invert elevation above datum (ft)	0.75
Number of orifices in set	3

☐ Use Random Number Generation to Account for Infiltration Rate Uncertainty

Initial Water Surface Elevation (ft): 0.00

Other Outlet (Add)

Stage Number	Stage (ft)	Other Outflow Rate (cfs)
1		
2		
3		
4		
5		

Evapotranspiration (Remove)

Soil porosity (saturation moisture content, 0-1)	0.390
Soil field moisture capacity (0-1)	0.138
Permanent wilting point (0-1)	0.045
Supplemental irrigation used?	☐
Fraction of available capacity when irrigation starts (0-1)	0.000
Fraction of available capacity when irrigation stops (0-1)	0.000

Evaporation (Add)

Month	Evapotranspiration (in/day)	Evaporation (in/day)
Jan	0.00	
Feb	0.00	
Mar	0.00	
Apr	0.10	
May	0.20	
Jun	0.40	
Jul	0.50	
Aug	0.40	
Sep	0.20	
Oct	0.10	
Nov	0.00	
Dec	0.00	

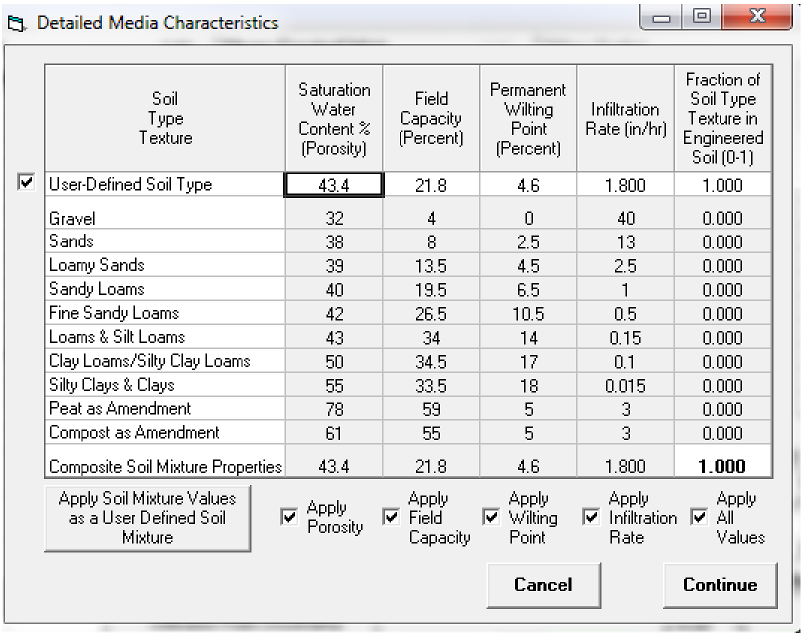
Plant Types

	1	2	3	4
Fraction of biofilter that is vegetated	1.00	0.00	0.00	0.00
Plant type	Prairie P			
Root depth (ft)	6.0	0.0	0.0	0.0
ET Crop Adjustment Factor	0.50	0.00	0.00	0.00

Biofilter Geometry Schematic

Basis data entry screen for biofilters and bioinfiltration stormwater controls.

The following figure is a screen shot used to select the engineered media mixture. The model calculated the porosity, field capacity, wilting point, and infiltration rates for many combinations based on laboratory and field tests. The model also calculates the removal of different sized particles in the runoff based on the media mixture.



	Soil Type Texture	Saturation Water Content % (Porosity)	Field Capacity (Percent)	Permanent Wilting Point (Percent)	Infiltration Rate (in/hr)	Fraction of Soil Type Texture in Engineered Soil (0-1)
☑	User-Defined Soil Type	43.4	21.8	4.6	1.800	1.000
	Gravel	32	4	0	40	0.000
	Sands	38	8	2.5	13	0.000
	Loamy Sands	39	13.5	4.5	2.5	0.000
	Sandy Loams	40	19.5	6.5	1	0.000
	Fine Sandy Loams	42	26.5	10.5	0.5	0.000
	Loams & Silt Loams	43	34	14	0.15	0.000
	Clay Loams/Silty Clay Loams	50	34.5	17	0.1	0.000
	Silty Clays & Clays	55	33.5	18	0.015	0.000
	Peat as Amendment	78	59	5	3	0.000
	Compost as Amendment	61	55	5	3	0.000
	Composite Soil Mixture Properties	43.4	21.8	4.6	1.800	**1.000**

☑ Apply Porosity
☑ Apply Field Capacity
☑ Apply Wilting Point
☑ Apply Infiltration Rate
☑ Apply All Values

Media characteristics used in the test (pilot) biofilters and bioinfiltration devices.

The bottom of the biofilter has a datum of zero. To describe the biofilter, the following information is entered:

Device Geometry:

Top Area (square feet): Enter the top area of the biofilter

Bottom Area (square feet): Enter the bottom area of the biofilter

Total Depth (feet): Enter the depth of the biofilter.

Typical Width (ft): If you intend to perform a cost analysis of the biofilter practices listed in the .mdb file, you must enter the typical biofilter width (ft) of a biofilter system you are modeling. This value is not used for a hydraulic or water quality analysis; it is relevant only for the cost analysis.

Native Soil Infiltration Rate (in/hr): Enter the infiltration rate or select a typical infiltration rate based on soil type from the provided list in the lower left-hand corner of the window. The native soil infiltration rate value is supplied if you select the typical seepage rate provided by the model.

Native Soil Infiltration Rate COV (Coefficient of Variation): If you want to consider the typical variabilities in the infiltration rates, select the “Use Random Number Generation to Account for Uncertainty in Infiltration Rate” checkbox and then accept or enter another seepage rate COV value in the cell below the native soil infiltration rate. This is optional and uses a Monte Carlo simulation built into the model. If selected, the infiltration rates are randomly varied for each event based on a log-normal probability distribution of actual measured infiltration rate variabilities.

Infiltration Rate Fraction - Bottom (0-1): Enter the seepage rate multiplier for bottom flow (from 0 to 1) to reduce the seepage rate through the bottom of the biofilter. This option can be useful if you want to evaluate the effects of complete clogging on the bottom of the device.

Infiltration Rate Fraction - Side (0-1): Enter the seepage rate multiplier for side flow (from 0 to 1) to reduce the seepage rate through either the sides of the biofilter. This option can be useful if you want to ignore the benefits of seepage out of the sides of the device, as required by some regulatory agencies.

Rock Filled Depth (ft): This is the depth of biofilter that is rock filled. This must be less than or equal to the biofilter depth, and may be zero if there is no rock fill. Water is assumed to flow through the rock storage layer very quickly.

Rock Fill Porosity: Enter the fraction of rock fill that is voids as a value from zero to one. If you have both rock fill and engineered soil, the model sums the total porosity available in the biofilter. If you are using an underdrain, a rock storage layer will be required (and the underdrain is usually located near the top of this storage layer).

Engineered Media Type. If the device has an engineered soil layer, the program uses an infiltration rate depending on the type of engineered media, based on extensive media tests in laboratory columns and in the field. Select the 'Media Data' button to enter media type information including the media porosity, infiltration rate, field moisture capacity and permanent wilting point.

Engineered Media Infiltration Rate (in/hr): If you have selected a specific engineered media type, the program uses an infiltration rate for that media type, or if you selected a user defined media type, you may enter your own engineered media infiltration rate.

Engineered Media Depth (ft). This must be less than or equal to the biofilter depth, and may be zero if there is no engineered media fill.

Engineered Media Porosity (0-1): This is the fraction of engineered media that is voids - enter the porosity of the engineered media as a value from zero to one. If you have both rock fill and engineered media, the model sums the total porosity volume from all layers.

Percent Solids Reduction Due to Engineered Media. If you want to enter a percent solids reduction value from engineered media if permitted to do so by the regulatory agency or because you have suitable data, select “User-Defined” as the engineered media type in the Detailed Soil Characteristics form. If you select any other engineered media type, the program calculates the percent reduction based on the media type.

Inflow Hydrograph Peak Flow to Average Flow Ratio. This value is used to determine the shape of the complex triangular unit hydrograph that is routed through the device. A typical value of the peak to average flow ratio is 3.8. However, short duration events in small areas may have larger ratios and similarly, long duration events in large areas may have smaller ratios. WinDETPOND can evaluate any inflow hydrograph shape that you enter. In version 10, it is recommended that the option to use the hydrograph from upgradient areas and controls be used instead of resetting this value to 3.8.

Number of Devices in the Source Area or Upstream Drainage System. The model divides the runoff volume by the number of biofilters in the source area or land use, creates a complex triangular hydrograph that it routes through that biofilter, and then multiplies the resulting losses by the number of biofilters to apply the results to the source area.

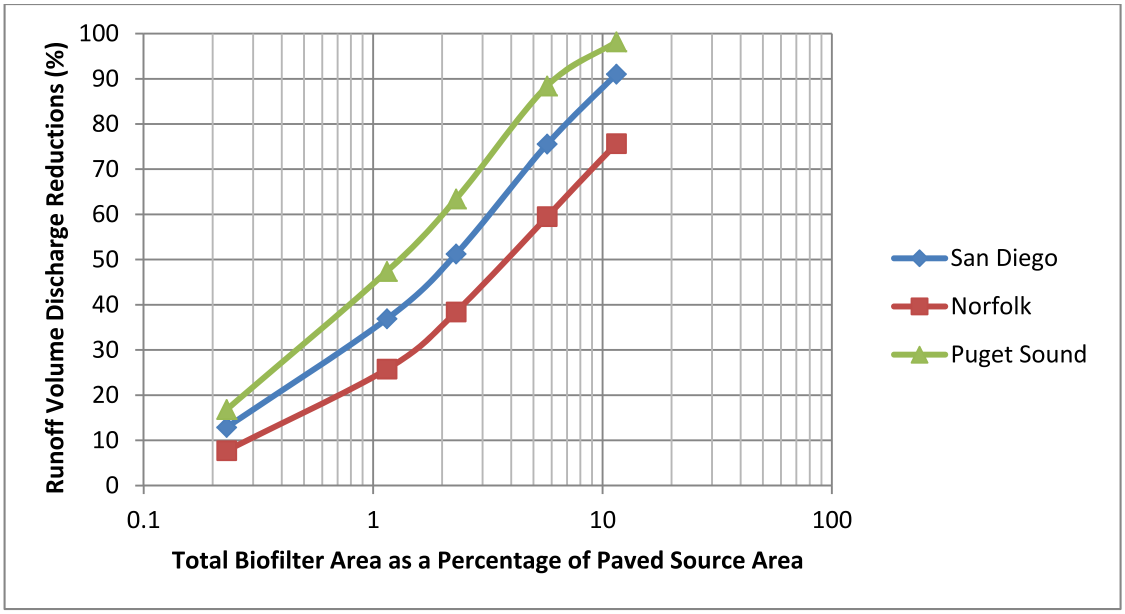
Particle Size Distribution File. The particle size distribution of the particulates in the runoff affects the percent solids reduction of the engineered media layer. The program uses pre-defined reductions for selected particle size distributions. If you have a user-defined engineered media type, then you do not need to enter a particle size distribution file. If you select the 'Route Hydrographs and Particle Sizes between Control Devices' checkbox in Program Options/Default Model Options, the program uses the default particle size distribution file for all source areas. The particle size distribution entering the control device is modified by whatever practices are upstream of the control practice. If the practice is the most upstream practice, the default particle size distribution is used.

Pipe or Box Storage is not activated in this model version.

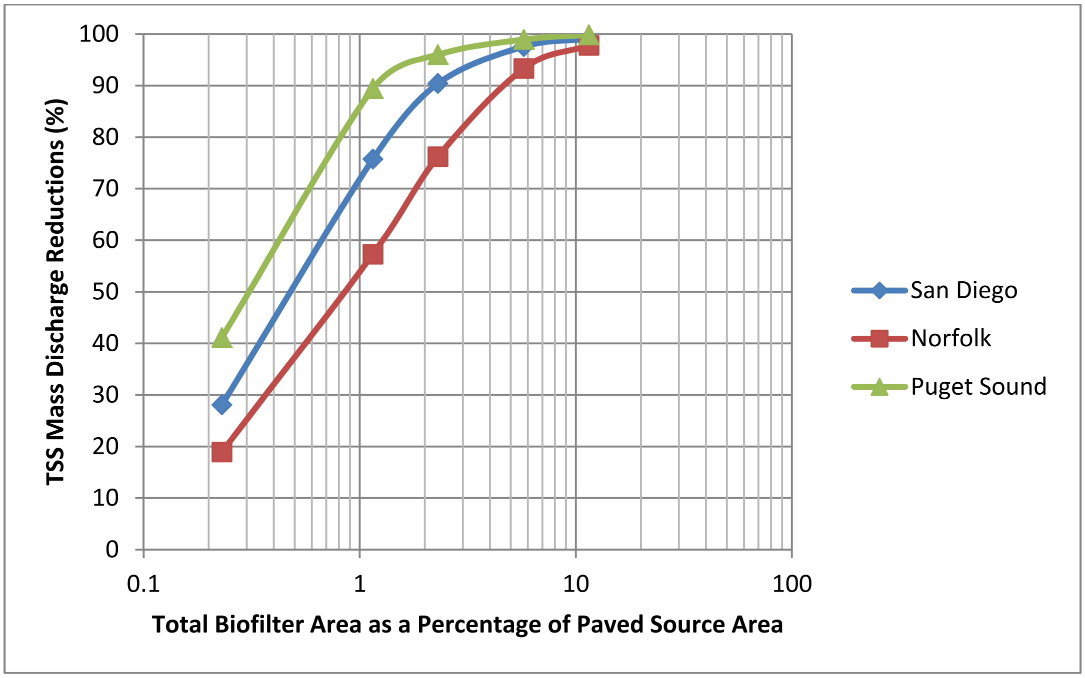
The following figures show the effects of biofilter size on performance for the three naval base locations. The basic biofilter was 100ft^2 at the top and 50ft^2 at the bottom and was 5 ft deep. It had 1.5 ft of a rock storage layer and 1.5 ft of media (75% sand and 25% peat amendment). A top ponding depth of 1.75 ft was also used. The surface overflow was a 10 ft wide broad-crested weir and it also had a SmartDrain located near the top of the rock layer. The native infiltration rate was for a loam soil at 0.5 in/hr. The performance for different sized biofilters was calculated by increasing the number of units per acre of paved area. These results were then normalized as a percentage of the paved area, as shown on these figures.

For low infiltration rates, conventional underdrains degrade the performance of the biofilters because the underdrains discharge subsurface ponding water before it can completely infiltrate. The use of a restricted flow underdrain (the SmartDrain^{TM}), results in a minimal effect on infiltration along with desired decreased durations of surface ponding. Underdrains have very little effect on performance when the native subsurface native infiltration rate is about 1 in/hr or greater.

In order to achieve about 90% runoff volume reductions, the biofilter areas would need to be about 6% for Puget Sound, about 12% for San Diego, and about 20% for Norfolk. The removal of particulates in the stormwater is greater than the runoff volume removals because the larger particulates are captured in the media before being discharged through the underdrain. TSS removals of about 90% occur when the biofilters are about 1% for Puget Sound, about 2% for San Diego, and about 5% for Norfolk.

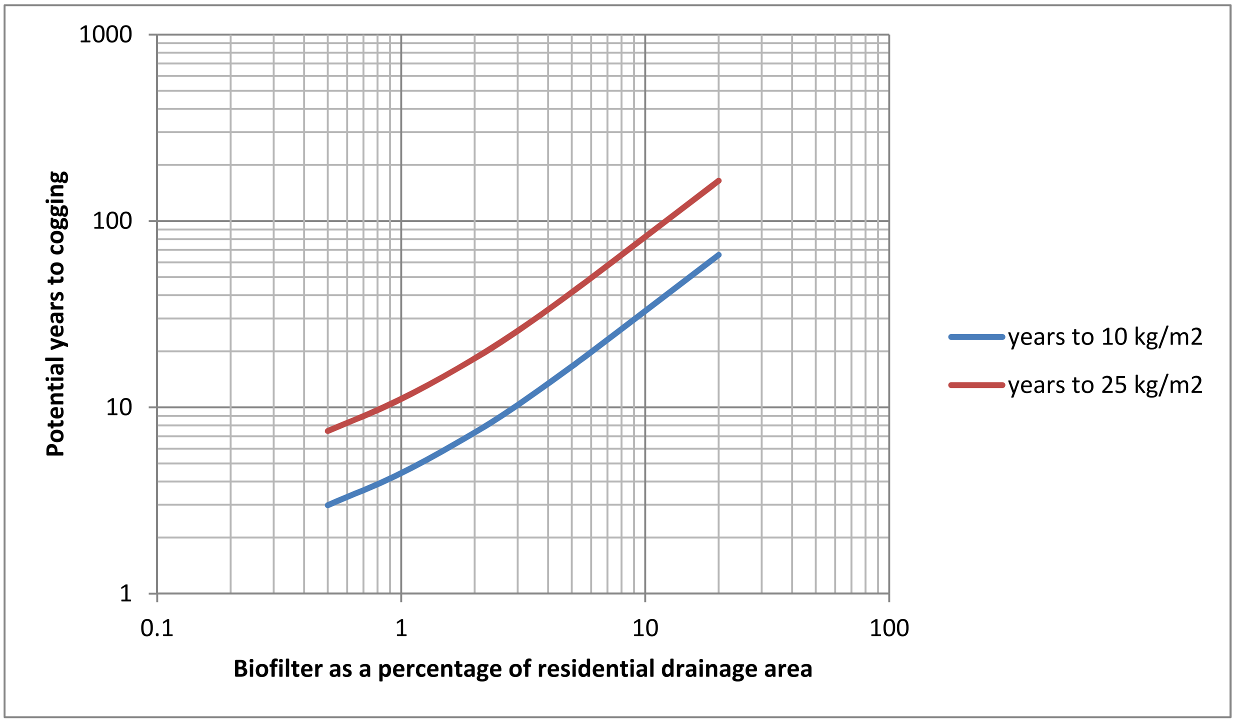


Runoff volume infiltration for different sized biofilters at three naval facility locations.



Particulate solids retention in biofilters for different sized biofilters at three naval base locaitons.

The following figure is a plot indicating the clogging potential for the biofilters for an example location in Kansas City. Biofilter media material is likely to fail resulting in very low infiltration rates with rapid and excessive particulate solids loadings. Generally, particulate loads of between 10 and 25 kg/m^2 could be indicative of significantly reduced infiltration. With a planted biofilter in good condition, and if this accumulative load occurs over at least 10 years, the biofilter is likely to be able to incorporate this additional material into the soil, and the plants can help retain the infiltration rate at a desired level (but with reduced surface storage volume). However, if this load occurs within just a few years, it is likely to overwhelm the system, resulting in premature clogging. This is more of a problem for small biofilters receiving runoff having high particulate solids concentrations, such as parking lots where space is limited for larger biofilters. Pretreatment using grass filters or swales can reduce these problems. For this example location, if the biofilters are at least 1 to 3% of the residential drainage area, the particulate loading is not likely to be a problem.



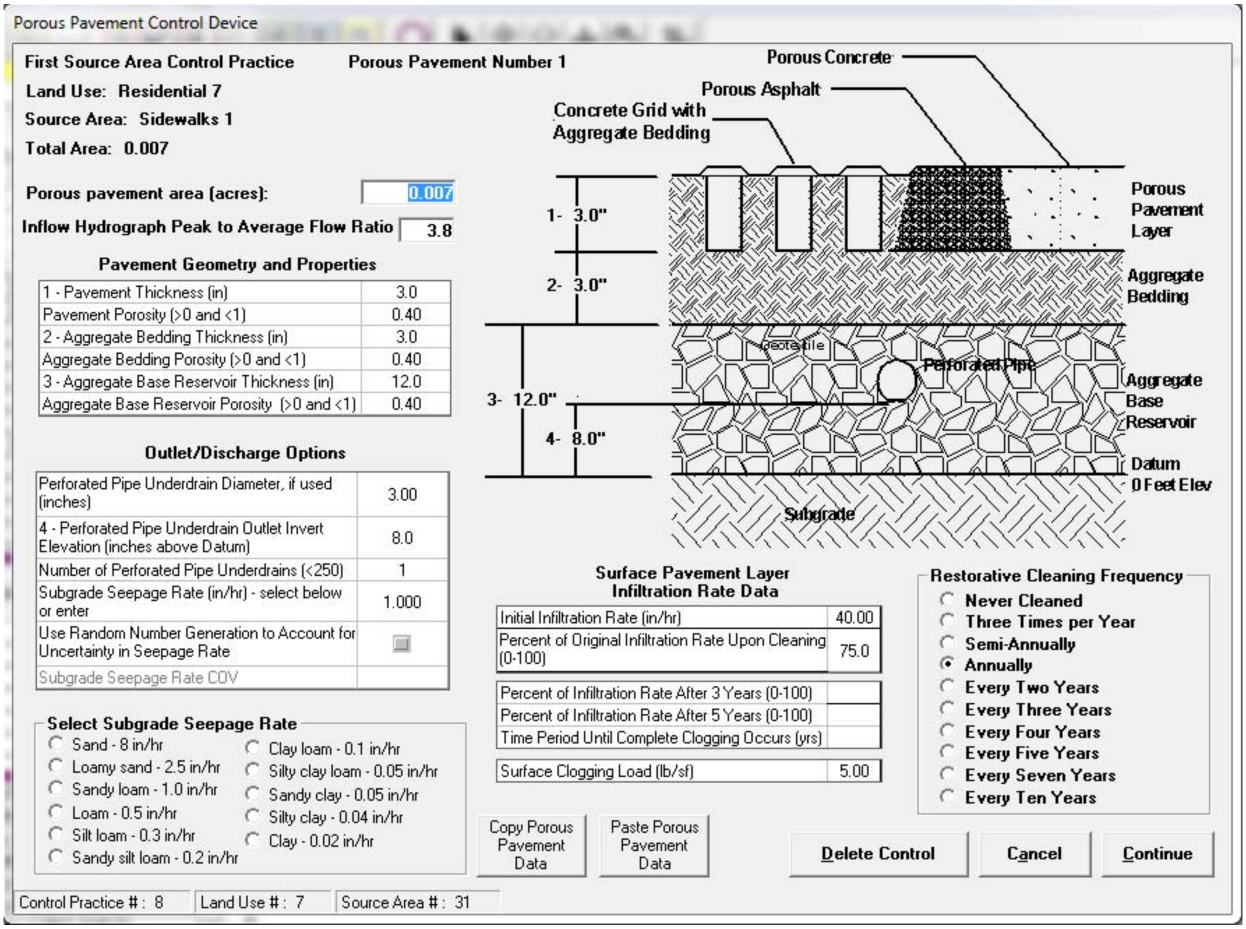
Clogging potential for biofilters in test (pilot) area.

Porous Pavement

The WinSLAMM porous pavement control in version 10 has full routing calculations associated with subsurface pond storage, and it allows runon from adjacent paved areas that do not have porous pavement. The *outlet* options for porous pavements include subgrade seepage and an optional underdrain, which is modeled as an orifice. The porous pavement control device has a surface seepage rate that limits the amount of runoff that can enter the storage system. The seepage rate is usually much greater than the rain intensity, so this would be unusual, except if it is significantly reduced by clogging or if substantial runon occurs from adjacent paved areas. This surface seepage rate is reduced to account for clogging with time, while the surface seepage rate can be partially restored with cleaning at a stated cleaning frequency. The runoff volume reaching the porous pavement surface is equal to the rainfall volume directly falling on the porous pavement, plus runoff volume from any runon from the adjacent paved areas. The porous pavement surface can be paver blocks, porous concrete, porous asphalt, or any other porous surface, including reinforced turf. Porous pavements are usually installed over a subsurface storage layer that can dramatically increase the infiltration performance of the device.

Porous pavements are typically used at paved parking and storage areas, paved playgrounds, paved driveways, or paved walkways. They should be used in relatively clean areas (walkways or driveways or other surfaces that receive little traffic, for example), to minimize groundwater contamination potential and premature clogging and failure. Porous pavements direct the infiltrating water to subsurface soil layers, usually at a depth where the soils have little organic matter that tend to sorb pollutants. Salts used for ice control in northern areas are also problematic when considering infiltrating stormwater. Consider biofiltration devices to infiltrate water from more contaminated sites because they can use amended soils to help trap contaminants before infiltration, or use other appropriate pre-treatment before infiltration, and are easier to restore. No common pretreatment device is suitable for removing salts, however, so minimal use of deicing chemicals is the preferred control option.

It is necessary to describe the geometry and other characteristics of a typical porous pavement surface, as shown in the following figure. The model computes the runoff volume, equal to the rainfall volume plus any runon, and then creates a complex triangular hydrograph (the flow duration equals the rain duration) that it routes through that porous pavement system.



Porous Pavement Control Device

First Source Area Control Practice   Porous Pavement Number 1

Land Use: Residential 7

Source Area: Sidewalks 1

Total Area: 0.007

Porous pavement area (acres): 0.007

Inflow Hydrograph Peak to Average Flow Ratio 3.8

Pavement Geometry and Properties

1 - Pavement Thickness (in)	3.0
Pavement Porosity (>0 and <1)	0.40
2 - Aggregate Bedding Thickness (in)	3.0
Aggregate Bedding Porosity (>0 and <1)	0.40
3 - Aggregate Base Reservoir Thickness (in)	12.0
Aggregate Base Reservoir Porosity (>0 and <1)	0.40

Outlet/Discharge Options

Perforated Pipe Underdrain Diameter, if used (inches)	3.00
4 - Perforated Pipe Underdrain Outlet Invert Elevation (inches above Datum)	8.0
Number of Perforated Pipe Underdrains (<250)	1
Subgrade Seepage Rate (in/hr) - select below or enter	1.000
Use Random Number Generation to Account for Uncertainty in Seepage Rate	☐
Subgrade Seepage Rate COV	

Select Subgrade Seepage Rate

○ Sand - 8 in/hr

○ Loamy sand - 2.5 in/hr

○ Sandy loam - 1.0 in/hr

○ Loam - 0.5 in/hr

○ Silt loam - 0.3 in/hr

○ Sandy silt loam - 0.2 in/hr

○ Clay loam - 0.1 in/hr

○ Silty clay loam - 0.05 in/hr

○ Sandy clay - 0.05 in/hr

○ Silty clay - 0.04 in/hr

○ Clay - 0.02 in/hr

Surface Pavement Layer Infiltration Rate Data

Initial Infiltration Rate (in/hr)	40.00
Percent of Original Infiltration Rate Upon Cleaning (0-100)	75.0

Percent of Infiltration Rate After 3 Years (0-100)	
Percent of Infiltration Rate After 5 Years (0-100)	
Time Period Until Complete Clogging Occurs (yrs)	

Surface Clogging Load (lb/sf)	5.00

Restorative Cleaning Frequency

○ Never Cleaned

○ Three Times per Year

○ Semi-Annually

● Annually

○ Every Two Years

○ Every Three Years

○ Every Four Years

○ Every Five Years

○ Every Seven Years

○ Every Ten Years

Control Practice # : 8   Land Use # : 7   Source Area # : 31

Porous pavement main input screen.

The next table summarizes the calculated performance of porous pavements located at paved parking/storage areas in an example location in Kansas City (expected to be intermediate for the three naval base sites). The given underlying soil is a loam soil. A conventional 3-in. perforated pipe underdrain was also used. As indicated, even the smallest area examined (25% of the area as porous pavement) had very good runoff volume reductions for this example. If the porous pavement was cleaned every year, much of the lost surface infiltration rate capacity would be restored for this example. If the area was not cleaned, clogging would be expected in about 8 years, based on field experience.

Porous pavement performance (paved parking and storage area; loam soil; 3-in underdrains placed 20 ft apart)

Porous pvt as a % of paved parking area	Volume reduction (%)
25%	92%
50%	93%
100%	93%

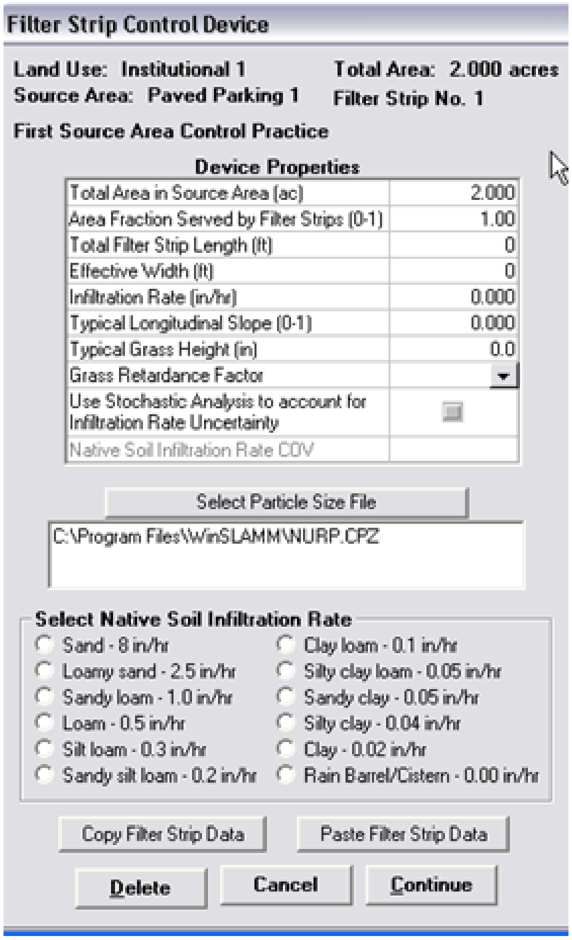
Grass Filters

Grass filters have broad, shallow flows. WinSLAMM determines the flow conditions for every calculation increment, including flow velocity and depth. Special shallow Manning's n values are used according to shallow sheetflow measurements. Sediment transport is calculated for each narrow particle size range using their sedimentation rate, depth of flow, and length of flow. Scour is also considered, along with equilibrium concentrations.

The grass filter and grass swale controls calculate pollutant and runoff volume reductions. The model determines the runoff volume reduction by calculating the infiltration loss for each time step. The particulate reduction is based on the settling frequency of the particles entering the grassed area and the height of the grass relative to the flow depth. The grass "filters" the runoff using the settling frequency and the length of the flow path. The algorithms used to determine the Manning's n values were developed from the master's thesis by Jason Kirby Kirby, *et al.* 2005) as part of a WERF-supported research project (Johnson, *et al*. 2003). The particle trapping algorithms were based on the master's thesis research conducted by Yukio Nara (Nara, *et al*. 2006), supported by the University Transportation Center for Alabama (Nara and Pitt 2005).

Runoff volume is reduced by the dynamic infiltration rate of the swales for each 6-minute time step of the hydrograph. The flow and the geometry are used to determine Manning's n to iteratively determine the depth of flow in the swale for each time step, using traditional VR-n curves that were extended by Kirby (Kirby, *et al.* 2005) to address the smaller flows found in roadside grass swales and filters. Using the calculated depth of flow for each time increment, the model calculates the wetted perimeter (using the swale cross-sectional shape), which is then multiplied by the total flow length to determine the area used to infiltrate the runoff. Details for these calculations are available by selecting the "Hydraulics Detailed Output File" checkbox from the "Detailed Output Options" listing under "Program Options." The event-by-event summary detailed output is available by selecting the "Hydraulics and Concentration by Event" checkbox from the Detailed Output Options listing. These comma-separated tabular files are created when the model is executed and can be reviewed using a spreadsheet after importing the files.

The next figure is the WinSLAMM basic input screen used for grass filters. As the grass filters become steep, they lose some of their performance because of the faster flowing has a greater equilibrium capacity associated with its carry capacity and the faster flowing water has reduced effective infiltration rates compared to ponded water. Version 10 uses a direct calculation of the hydraulics for grass filter strips as for grass swales, but with modified turbulent induced length restrictions. An upcoming model release will use Muskingum channel routing to more effectively calculate the flowing water conditions in the grass filters (and swales).



Land Use: Institutional 1
Source Area: Paved Parking 1
Total Area: 2.000 acres
Filter Strip No. 1

First Source Area Control Practice

Device Properties

Total Area in Source Area (ac)	2.000
Area Fraction Served by Filter Strips (0-1)	1.00
Total Filter Strip Length (ft)	0
Effective Width (ft)	0
Infiltration Rate (in/hr)	0.000
Typical Longitudinal Slope (0-1)	0.000
Typical Grass Height (in)	0.0
Grass Retardance Factor	
Use Stochastic Analysis to account for Infiltration Rate Uncertainty	☐
Native Soil Infiltration Rate COV	

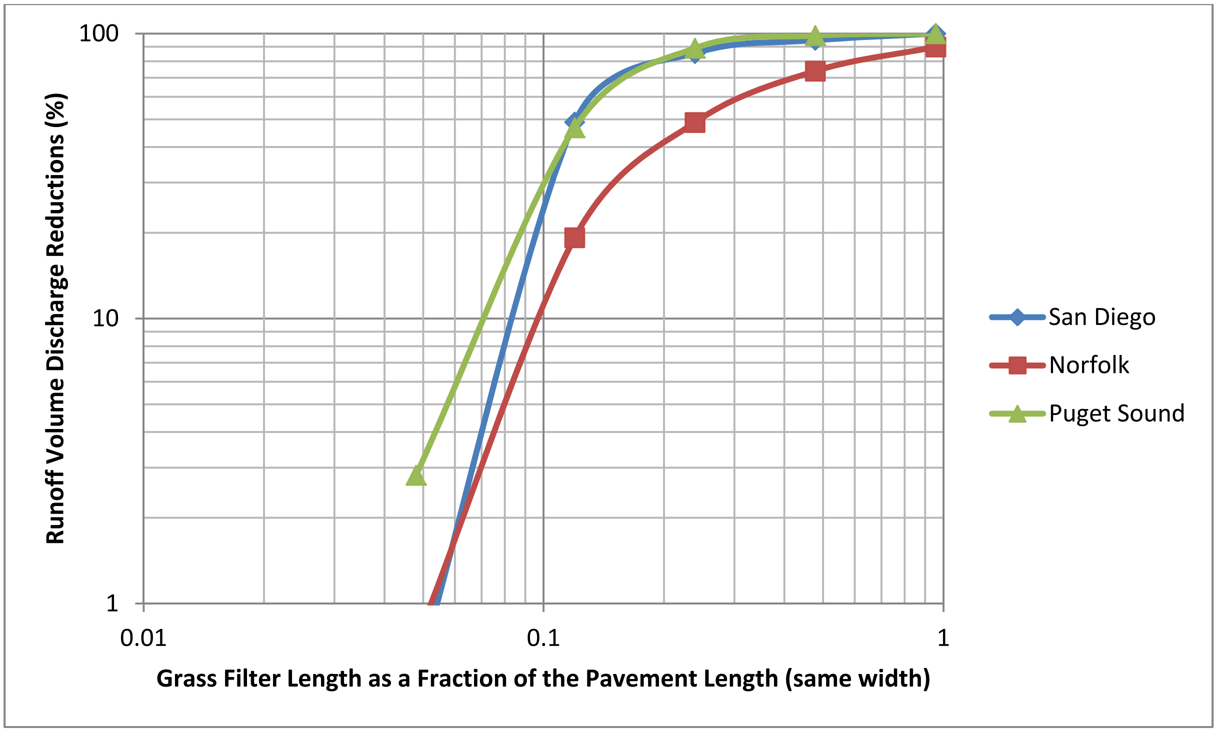
C:\Program Files\WinSLAMM\NURP.CPZ

Select Native Soil Infiltration Rate

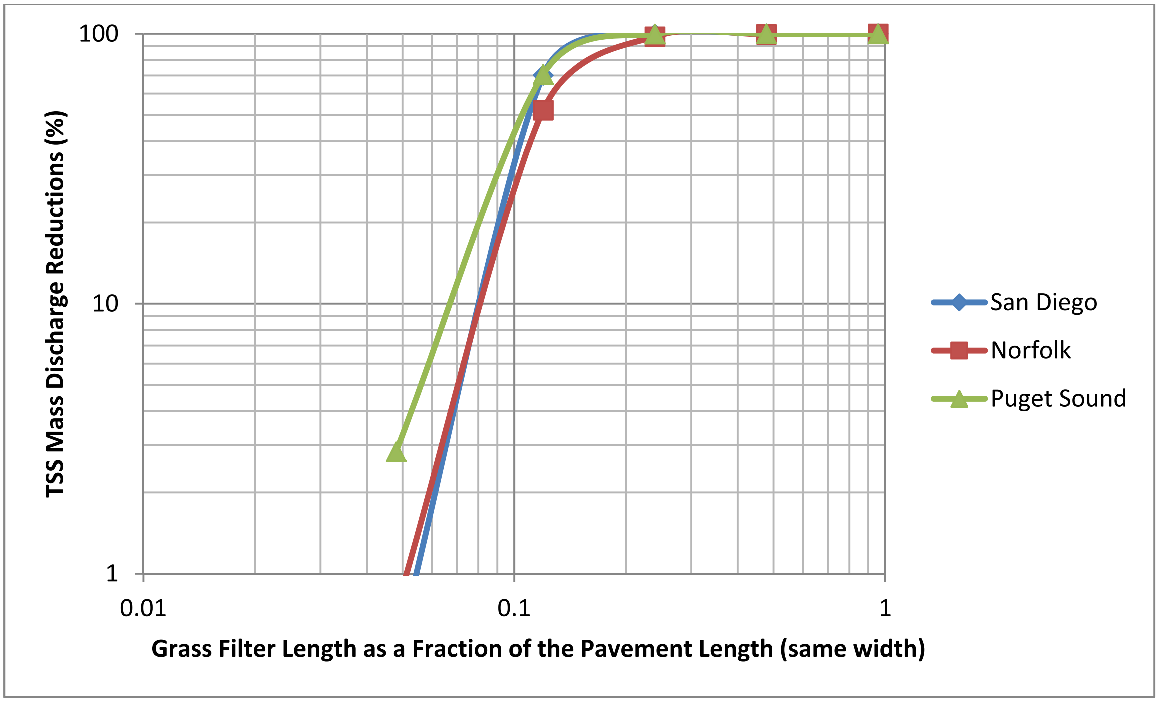
○ Sand - 8 in/hr	○ Clay loam - 0.1 in/hr
○ Loamy sand - 2.5 in/hr	○ Silty clay loam - 0.05 in/hr
○ Sandy loam - 1.0 in/hr	○ Sandy clay - 0.05 in/hr
○ Loam - 0.5 in/hr	○ Silty clay - 0.04 in/hr
○ Silt loam - 0.3 in/hr	○ Clay - 0.02 in/hr
○ Sandy silt loam - 0.2 in/hr	○ Rain Barrel/Cistern - 0.00 in/hr

Grass filter strip form in Version 10.

The following figures summarize the performance of grass filters for controlling runoff and TSS from paved areas. For these calculations, the grass filter was assumed to be as wide as the source area paved area and the length is expressed as a fraction of the length of the paved area. Loam soil having 0.25 in/hr infiltration rates were used along with a filter slope of 1% with 3 inch tall grass (D retardance class). Runoff infiltration performance was similar for the two west coast sites, but Norfolk was much less efficient due to the greater rainfall amounts and intensities at that location. Grass filters about 25% of the length of the paved area would result in about 90% runoff volume reductions at San Diego and Puget Sound, but would have to be close to 100% of the paved area length for the same level of performance for the Norfolk location. As the stormwater flows across the grass filter, it slows and particulates settle out of the flowing water and become trapped in the grass. The TSS mass reductions are therefore much greater than for the runoff volume reductions alone. Approximate 90% TSS mass reductions would occur for grass filters only about 15 to 20% of the pavement length, for example.



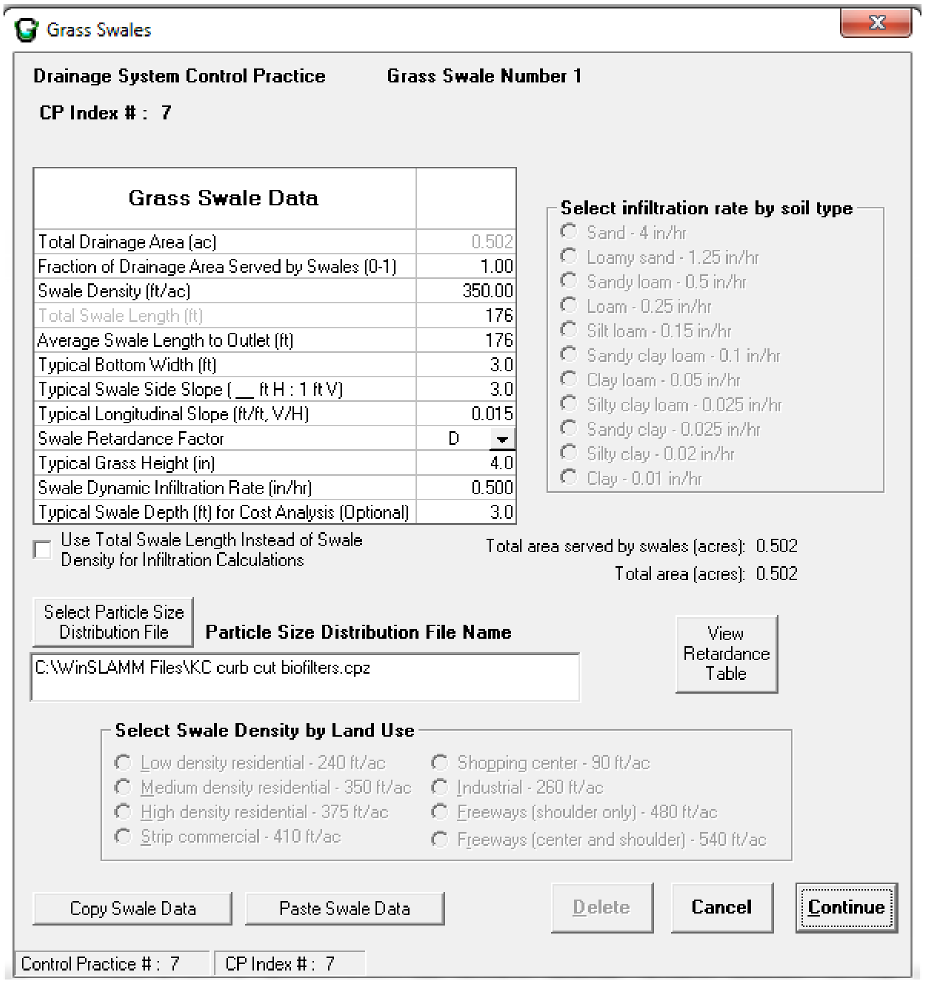
Runoff volume removals for different lengths of grass filter strips.



TSS mass discharge reductions for different lengths of grass filter strips.

Grass Swales

Grass swales are evaluated using the same general process as described previously for grass filters. The data entry form is shown in the next figure. Following figures summarize the performance of grass swales different lengths of swales compared to the drainage area for the three naval facility locations. These swales have 5 ft bottom widths with 3:1 side slopes and 1.5% longitudinal slopes. The grass is 3 inches tall with D retardance group. A loam soil having a 0.25 in/hr dynamic infiltration rate was also used in these calculations. The swale water volume and pollutant reduction performance would be better for increased infiltration rates.



Drainage System Control Practice   Grass Swale Number 1

CP Index # : 7

Grass Swale Data	
Total Drainage Area (ac)	0.502
Fraction of Drainage Area Served by Swales (0-1)	1.00
Swale Density (ft/ac)	350.00
Total Swale Length (ft)	176
Average Swale Length to Outlet (ft)	176
Typical Bottom Width (ft)	3.0
Typical Swale Side Slope (__ ft H : 1 ft V)	3.0
Typical Longitudinal Slope (ft/ft, V/H)	0.015
Swale Retardance Factor	D
Typical Grass Height (in)	4.0
Swale Dynamic Infiltration Rate (in/hr)	0.500
Typical Swale Depth (ft) for Cost Analysis (Optional)	3.0

Select infiltration rate by soil type
○ Sand - 4 in/hr
○ Loamy sand - 1.25 in/hr
○ Sandy loam - 0.5 in/hr
○ Loam - 0.25 in/hr
○ Silt loam - 0.15 in/hr
○ Sandy clay loam - 0.1 in/hr
○ Clay loam - 0.05 in/hr
○ Silty clay loam - 0.025 in/hr
○ Sandy clay - 0.025 in/hr
○ Silty clay - 0.02 in/hr
○ Clay - 0.01 in/hr

☐ Use Total Swale Length Instead of Swale Density for Infiltration Calculations

Total area served by swales (acres): 0.502
Total area (acres): 0.502

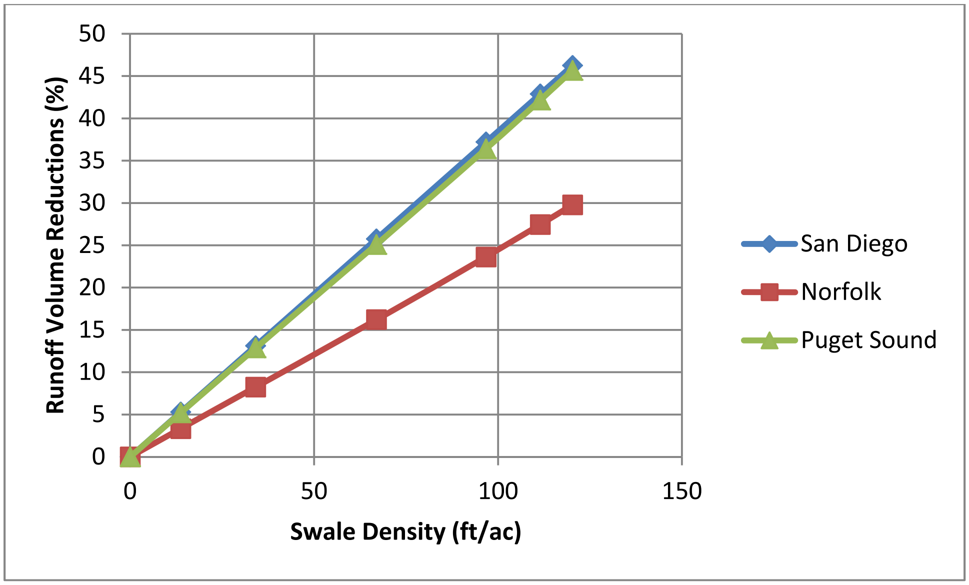
Particle Size Distribution File Name
C:\WinSLAMM Files\KC curb cut biofilters.cpz

Select Swale Density by Land Use
○ Low density residential - 240 ft/ac
○ Medium density residential - 350 ft/ac
○ High density residential - 375 ft/ac
○ Strip commercial - 410 ft/ac
○ Shopping center - 90 ft/ac
○ Industrial - 260 ft/ac
○ Freeways (shoulder only) - 480 ft/ac
○ Freeways (center and shoulder) - 540 ft/ac

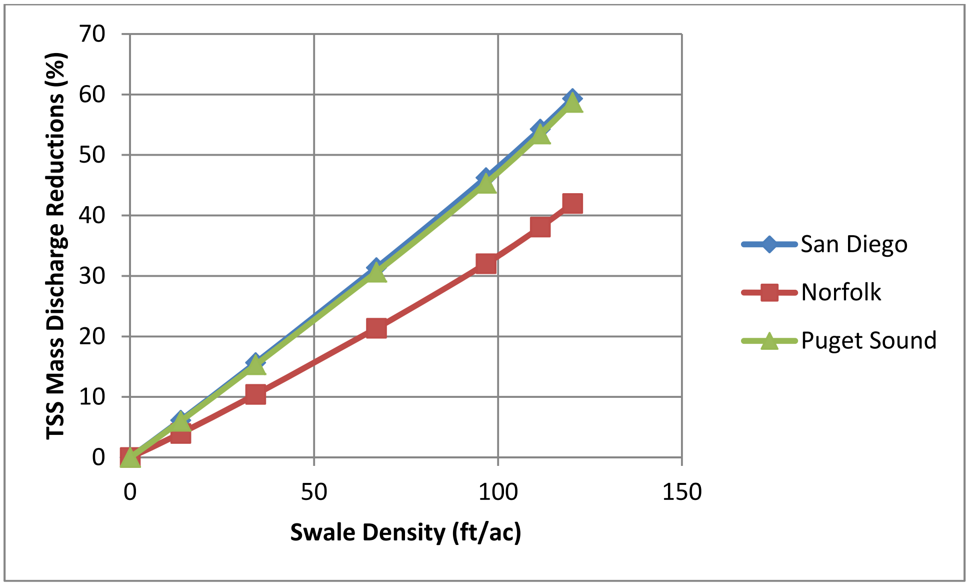
Control Practice # : 7   CP Index # : 7

Grass swale input screen.

These figures indicate similar performance for the west coast sites with poorer performance for the Norfolk location (as shown for the grass filters). Since the soil has a relatively low infiltration rate, the maximum runoff volume reductions are only about 50%, while the TSS reductions are somewhat larger due to the settling of particulates.



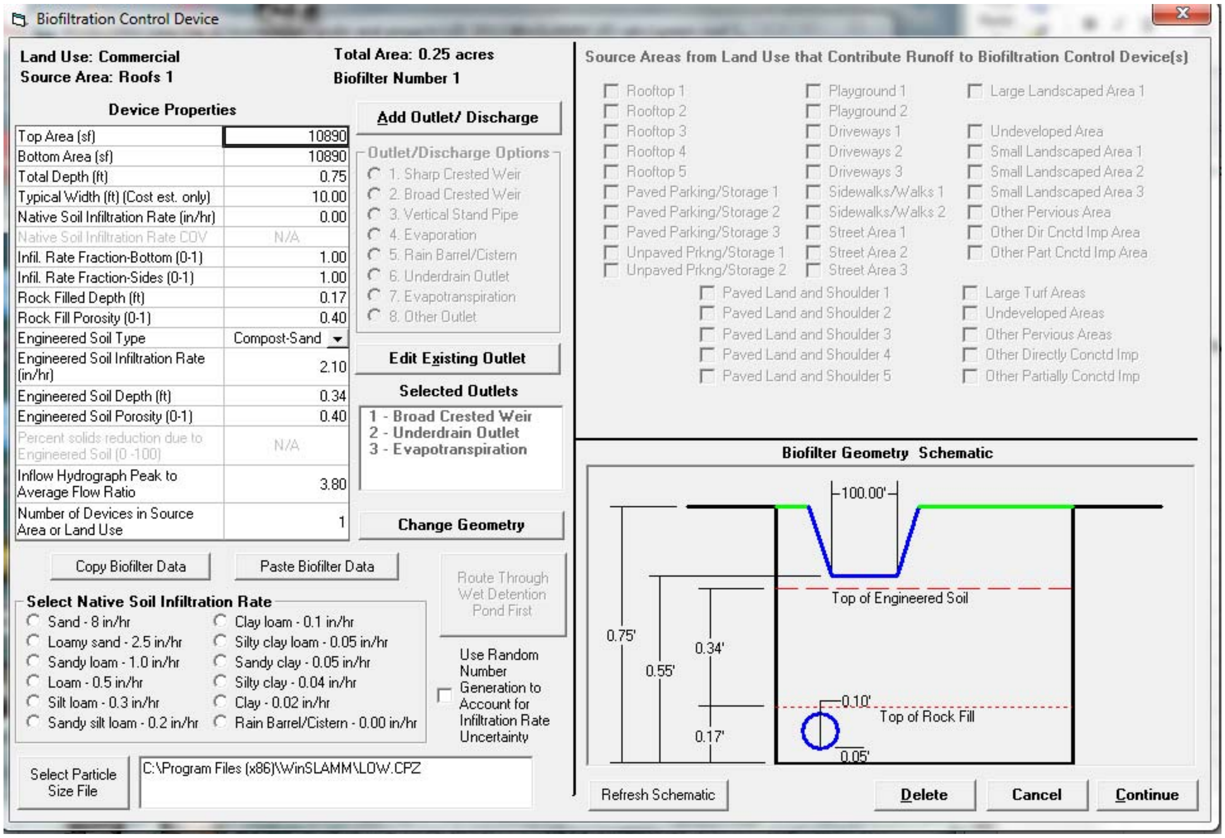
Runoff volume reductions for grass swales.



TSS mass discharge reductions for grass swales.

Green Roofs

As noted above for the description of the biofilter calculations, the biofilter device can be configured to represent green roofs, as illustrated in the next figure. In an upcoming WinSLAMM version, a separate screen will be provided for these devices. Basically, the green roof area is used as the area of the biofilter, and no natural infiltration is allowed. The only outlets include the required broad crested weir for surface overflows, underdrains, and ET. Partial roof coverage can be modeled by using a smaller area for the "biofilter" to represent the area dedicated to green roof processes.



Biofiltration Control Device

Land Use: Commercial
Source Area: Roofs 1
Total Area: 0.25 acres
Biofilter Number 1

Device Properties

Top Area (sf)	10890
Bottom Area (sf)	10890
Total Depth (ft)	0.75
Typical Width (ft) (Cost est. only)	10.00
Native Soil Infiltration Rate (in/hr)	0.00
Native Soil Infiltration Rate COV	N/A
Infil. Rate Fraction-Bottom (0-1)	1.00
Infil. Rate Fraction-Sides (0-1)	1.00
Rock Filled Depth (ft)	0.17
Rock Fill Porosity (0-1)	0.40
Engineered Soil Type	Compost-Sand
Engineered Soil Infiltration Rate (in/hr)	2.10
Engineered Soil Depth (ft)	0.34
Engineered Soil Porosity (0-1)	0.40
Percent solids reduction due to Engineered Soil (0 -100)	N/A
Inflow Hydrograph Peak to Average Flow Ratio	3.80
Number of Devices in Source Area or Land Use	1

Selected Outlets

1 - Broad Crested Weir
2 - Underdrain Outlet
3 - Evapotranspiration

Select Particle Size File: C:\Program Files (x86)\WinSLAMM\LOW.CPZ

Green roof main input screen.

The next table summarizes the calculated performance of the specified green roof system, for different roof coverages, for an example location in Kansas City. The effluent concentrations are similar for all scenarios because almost all of the water is filtered by the roof media, with little being discharged to the surface overflows. The available ET for that area resulted in a maximum of about 25% reductions in runoff volume discharges. If more surface storage was provided in the green roof design and if more efficient plants were used, it is likely that these runoff volume reductions could be about double the reductions shown in this example. It is expected that the San Diego location would have greater benefits for green roofs, while it would be less for the other two locations. Locally monitored evapotranspiration and selection of suitable plants are critical for an effective green roof installation, and those conditions are too varied to allow a simple analysis at the naval facilities.

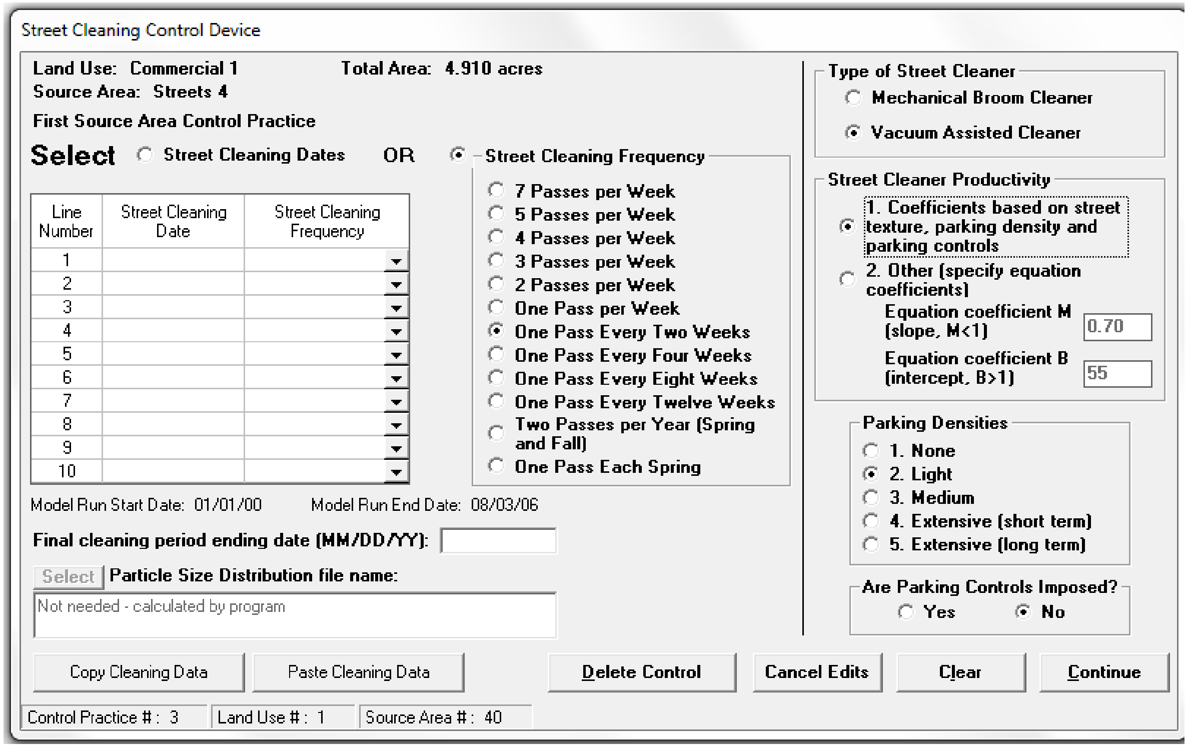
Calculated green roof performance

Green roof as a % of flat roof area (3-in conventional underdrains every 20 ft)	Volume reductions (%)
25%	11
50%	18
100%	25

Street Cleaning

Street cleaning affects the amount of street dust and dirt available for washoff during rains. Frequent street cleaning can reduce the loading of this material to very low levels. However, street cleaning preferentially removes the largest particles on streets, while rains preferentially remove the smallest particles. Therefore, the amount of material collected by a street cleaner is not directly related to the amount of particulates that would have washed during rains.

The next figure is the street cleaning form. Street cleaning control can be applied to streets and alleys in all land uses, including freeways. There are two options for entering in street cleaning dates. 1) Enter Street Cleaning Dates, or 2) Enter a Street Cleaning Frequency. Select the 'Street Cleaning Frequency' check box, and then the desired cleaning frequency is the most direct way to describe the street cleaning effort.



Street Cleaning Control Device

Land Use: Commercial 1   Total Area: 4.910 acres
Source Area: Streets 4
First Source Area Control Practice

Select ○ Street Cleaning Dates OR ● Street Cleaning Frequency

Line Number	Street Cleaning Date	Street Cleaning Frequency
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

Street Cleaning Frequency
- ○ 7 Passes per Week
- ○ 5 Passes per Week
- ○ 4 Passes per Week
- ○ 3 Passes per Week
- ○ 2 Passes per Week
- ○ One Pass per Week
- ● One Pass Every Two Weeks
- ○ One Pass Every Four Weeks
- ○ One Pass Every Eight Weeks
- ○ One Pass Every Twelve Weeks
- ○ Two Passes per Year (Spring and Fall)
- ○ One Pass Each Spring

Model Run Start Date: 01/01/00   Model Run End Date: 08/03/06

Final cleaning period ending date (MM/DD/YY):

Particle Size Distribution file name: Not needed - calculated by program

Type of Street Cleaner
- ○ Mechanical Broom Cleaner
- ● Vacuum Assisted Cleaner

Street Cleaner Productivity
- ● 1. Coefficients based on street texture, parking density and parking controls
- ○ 2. Other (specify equation coefficients)

Equation coefficient M (slope, M<1): 0.70
Equation coefficient B (intercept, B>1): 55

Parking Densities
- ○ 1. None
- ● 2. Light
- ○ 3. Medium
- ○ 4. Extensive (short term)
- ○ 5. Extensive (long term)

Are Parking Controls Imposed? ○ Yes ● No

Control Practice # : 3   Land Use # : 1   Source Area # : 40

Street cleaning form.

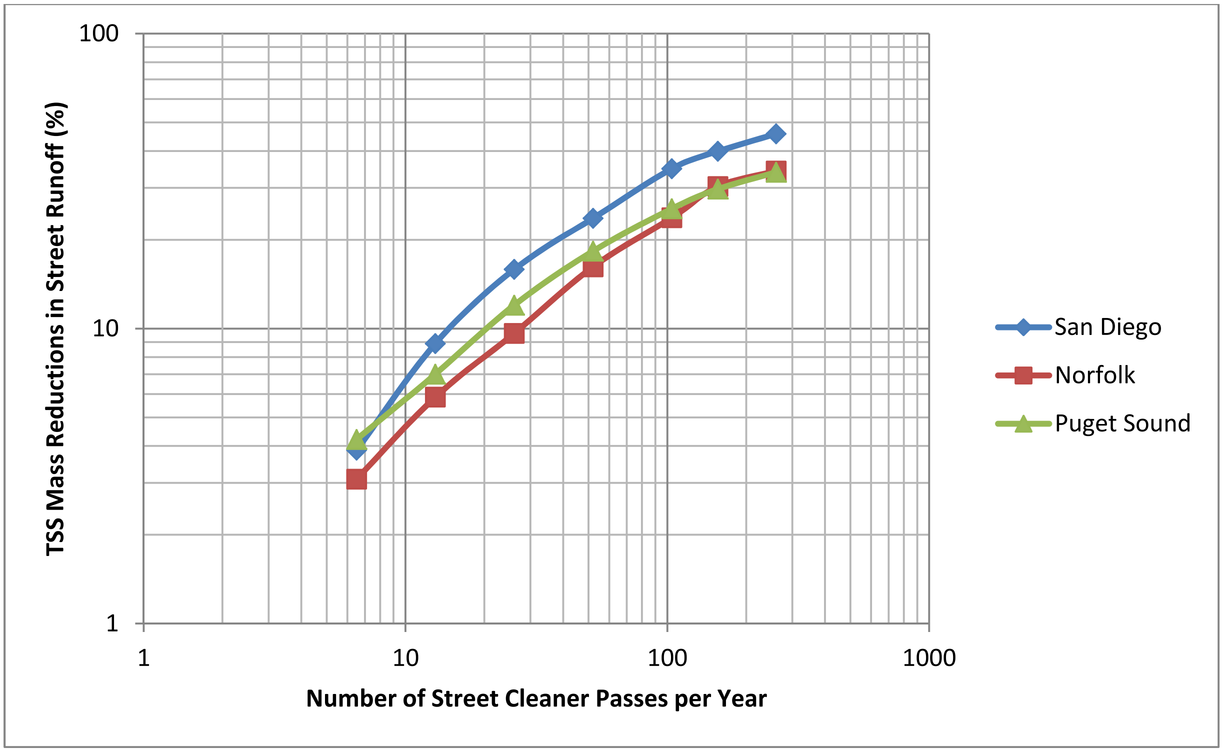
Type of Street Cleaner. Select the type of street cleaner. The program will enter the proper removal coefficients after you have selected the street cleaner productivity, parking density and parking control option.

Street cleaning productivity. Select the default productivity by entering the parking density and the parking control status. The parking density options are:

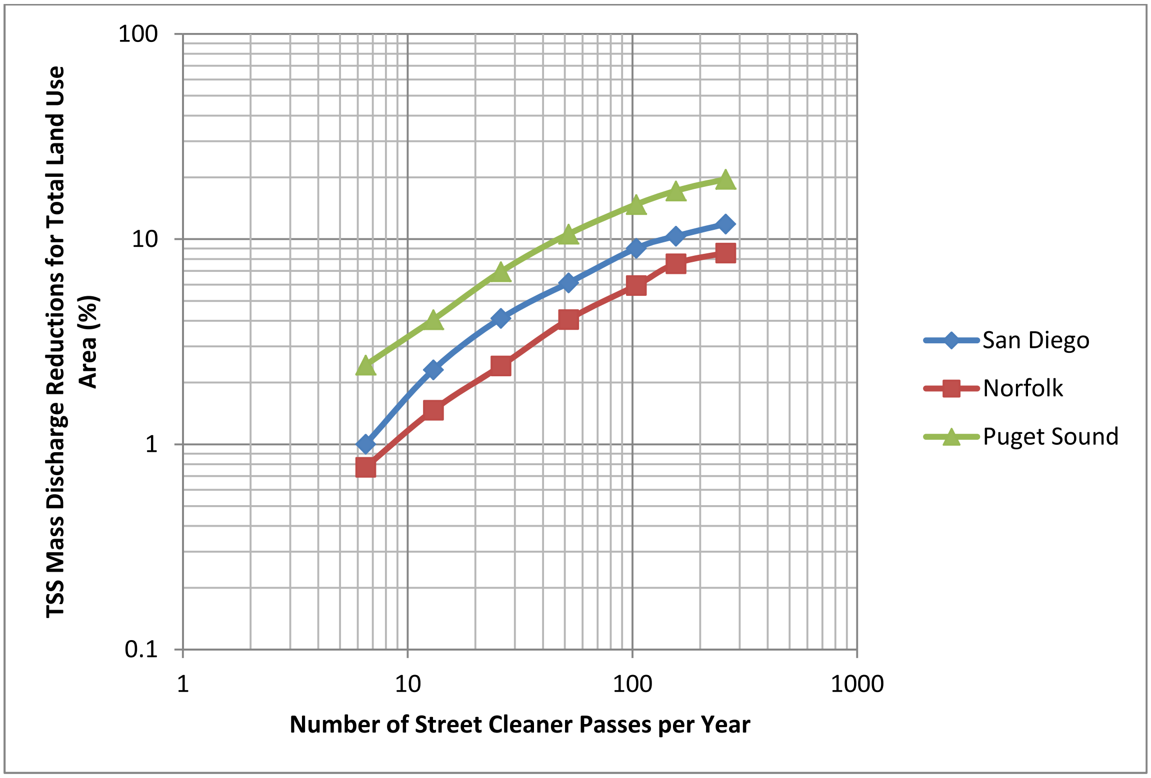
1. None - There is no parking along the street being cleaned.
2. Light - There is significant spacing between parked cars such that street cleaners can easily get to the curb, between cars, for significant sections of the street.
3. Medium - There is enough spacing between parked cars such that street cleaners can get to the curb for at least some sections of the street.
4. Extensive (short term) - There is not enough space between cars to allow street cleaners to get to the curb for some time during a 24-hour period.
5. Extensive (long term) - There is not enough space between cars to allow street cleaners to get to the curb. This condition persists for most or all of a 24-hour period.

The parking control status indicates whether parking options such as limited parking hours or alternate side-of-the-street parking have been regulated by the municipality.

The following figures are production function plots showing the expected TSS mass removals. The first figure shows the expected TSS reductions for just the street runoff, while the next figure shows the expected TSS reductions for the runoff for the whole area. In these examples, street areas are about 15% of the total area, while streets contributed about 26% of the total area runoff for San Diego and Norfolk, and about 58% of the total runoff for the Puget Sound area for the long-term analyses. A vacuum-assisted street cleaner was used in these calculations, along with intermediate textured streets having light parking and no parking controls. If the drainage area was mostly comprised of streets, then street cleaning once a week may results in about 15 to 25% TSS reductions.



Street cleaning performance for street runoff.

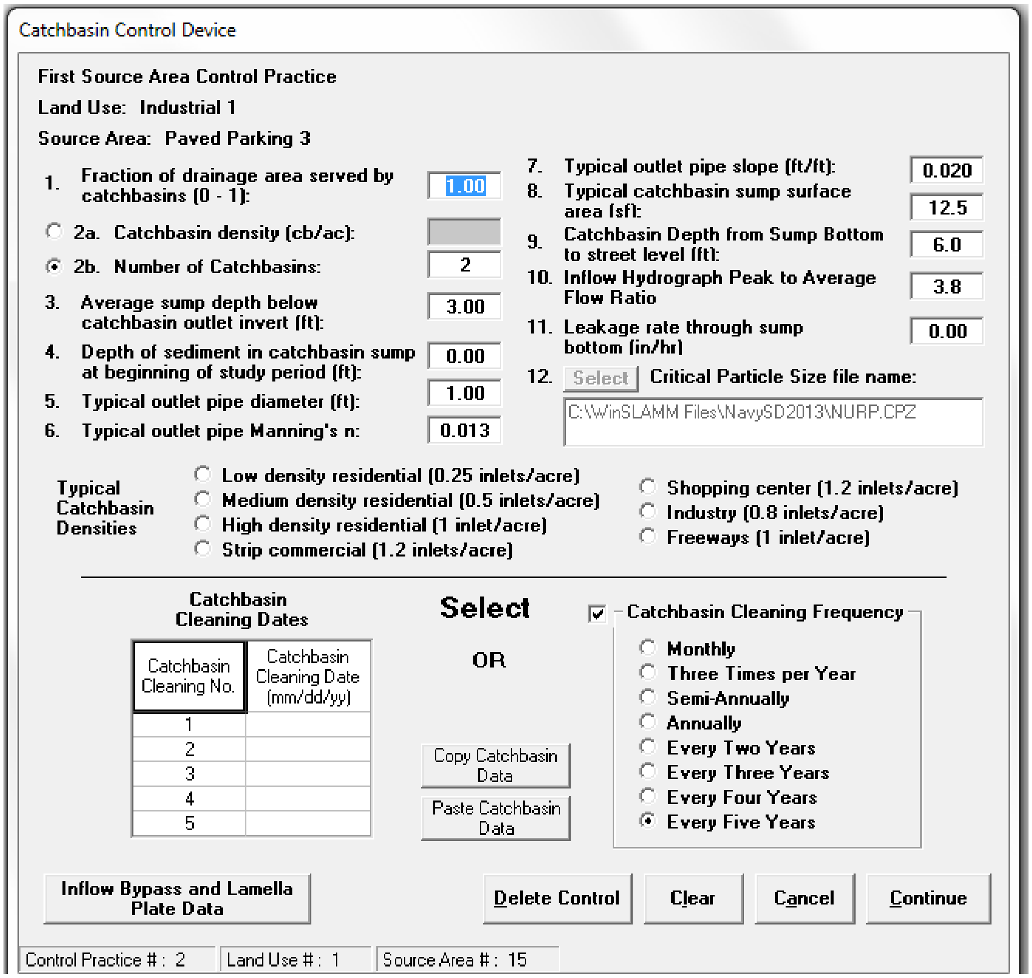


Street cleaning performance for watershed runoff.

Catchbasins and Hydrodynamic Separators

Catchbasins and hydrodynamic devices can be applied to either a specific source area or as part of the drainage system. Treatment is due to particle settling unless there is leakage through the bottom of the sump, which is considered as a runoff volume loss to the system. The program will calculate the percent of the total catchbasin volume that is full of captured sediment for each rainfall event. This value is reset to zero based upon when the catchbasin is cleaned.

Catchbasins are modelled as vertical walled detention basins with a pipe outlet. However, because they are small, they have negligible storage volume, so the storage component of the detention pond algorithm is not applied. Pipe outlet flow is calculated as the flow rate through a partially filled pipe or as orifice flow, whichever is smaller. The total flow to the catchbasin is divided by the number of catchbasins to determine the flow a typical catchbasin. The following figure is the catchbasin entry form.



First Source Area Control Practice
Land Use: Industrial 1
Source Area: Paved Parking 3

1. Fraction of drainage area served by catchbasins (0 - 1): 1.00
○ 2a. Catchbasin density (cb/ac):
● 2b. Number of Catchbasins: 2
3. Average sump depth below catchbasin outlet invert (ft): 3.00
4. Depth of sediment in catchbasin sump at beginning of study period (ft): 0.00
5. Typical outlet pipe diameter (ft): 1.00
6. Typical outlet pipe Manning's n: 0.013
7. Typical outlet pipe slope (ft/ft): 0.020
8. Typical catchbasin sump surface area (sf): 12.5
9. Catchbasin Depth from Sump Bottom to street level (ft): 6.0
10. Inflow Hydrograph Peak to Average Flow Ratio: 3.8
11. Leakage rate through sump bottom (in/hr): 0.00
12. Select Critical Particle Size file name: C:\WinSLAMM Files\NavySD2013\NURP.CPZ

Typical Catchbasin Densities
○ Low density residential (0.25 inlets/acre)
○ Medium density residential (0.5 inlets/acre)
○ High density residential (1 inlet/acre)
○ Strip commercial (1.2 inlets/acre)
○ Shopping center (1.2 inlets/acre)
○ Industry (0.8 inlets/acre)
○ Freeways (1 inlet/acre)

Catchbasin Cleaning Dates

Catchbasin Cleaning No.	Catchbasin Cleaning Date (mm/dd/yy)
1	
2	
3	
4	
5	

OR

☑ Catchbasin Cleaning Frequency
○ Monthly
○ Three Times per Year
○ Semi-Annually
○ Annually
○ Every Two Years
○ Every Three Years
○ Every Four Years
● Every Five Years

Control Practice # : 2 Land Use # : 1 Source Area # : 15

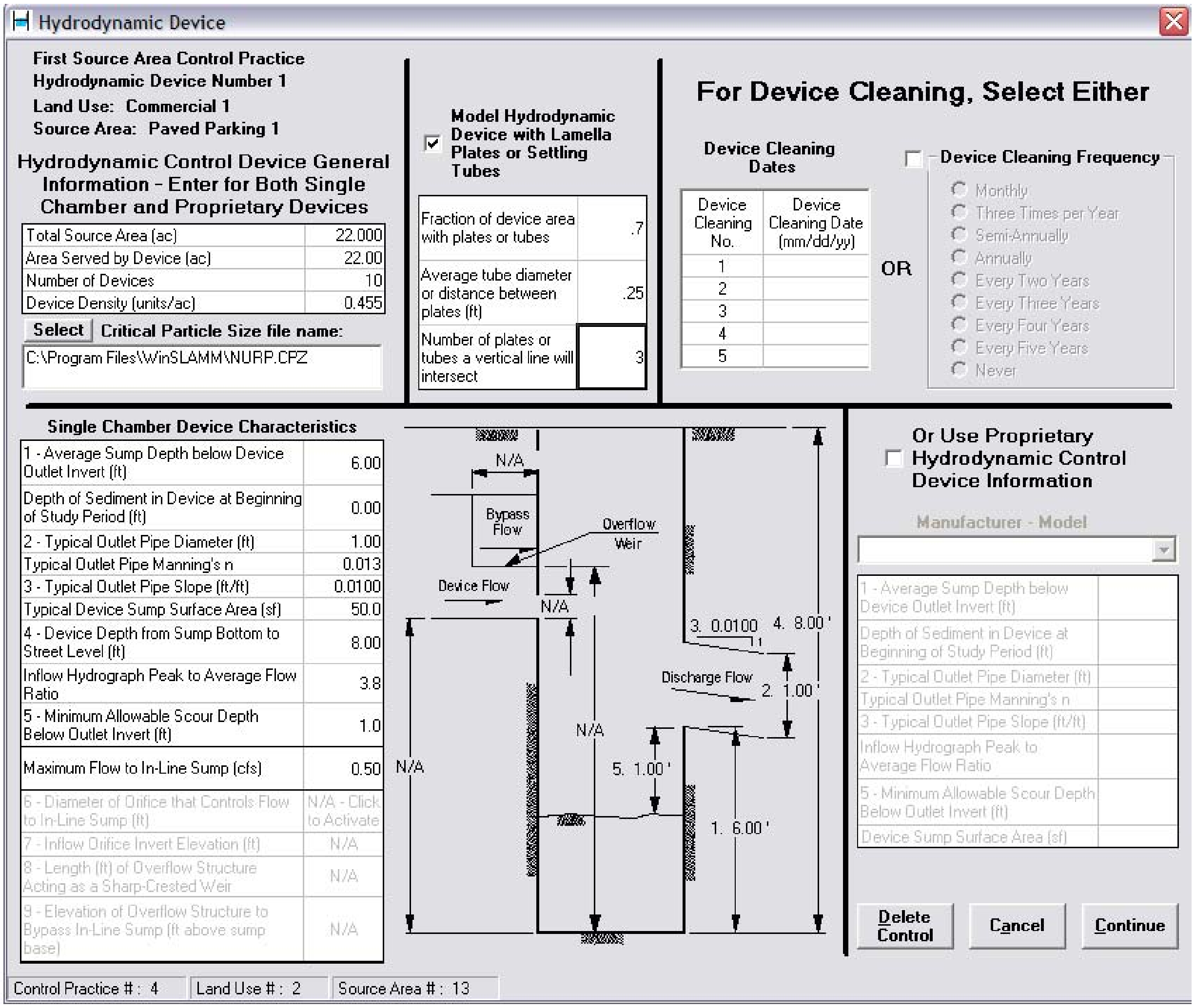
Catchbasin entry screen.

To model Catchbasin Performance, enter the following information in the form:

1. Fraction of drainage area served by catchbasin (0-1).
2a. The catchbasin density (using either typical catchbasin densities provided or enter in your site-specific value), or
2b. The number of catchbasins in the site you are modelling.
3. The Average Sump Depth below the catchbasin outlet invert (ft). Note that the model assumes that the top foot of storage volume is unavailable for storage due to scour. Therefore, the sump depth must be greater than 1.0 ft in order for the catchbasin to function. The catchbasin is considered 100% full when the sump depth less the scour depth is reached.
4. Depth of sediment in catchbasin sump at the beginning of the study period (ft).
5. Typical outlet pipe diameter (ft)
6. Typical outlet pipe Manning's n
7. Typical outlet pipe slope (ft/ft).
8. Typical catchbasin sump surface area (sq. ft)
9. Catchbasin depth from sump bottom to street level (ft). This value should be the sum of the average sump depth, the pipe diameter, the pipe wall thickness, and the typical cover over the pipe from the top of the pipe to the street surface.
10. The inflow hydrograph peak-to-average flow ratio. A typical value is 3.8; change it if you have better data.
11. Leakage rate through the sump bottom (in/hr). This value is used to model catchbasins that do not have sealed sumps. However, the impact on catchbasin effectiveness is typically minimal because the leaky sump areas are small.
12. Critical particle size file name. If you have checked the 'Route Hydrographs and Particle Sizes Between Control Devices' box in Program Options/Default Model Options, then the program will use the default particle size distribution file for all source areas. The particle size distribution entering the control device will be modified by whatever practices are upstream of the control practice. If the practice is the most upstream practice, then the default particle size distribution is used.

To enter catchbasin cleaning dates to model catchbasin cleaning, you can select either:
a. Catchbasin Cleaning Dates, which are the dates that the catchbasin is cleaned (ie, the % full value is reset to zero) during the study period (cleaning up to 5 times is allowed). The dates must be consecutive, within the study time period, and in the format "MM/DD/YY", or . . .
b. The Catchbasin Cleaning Frequency. The catchbasins will be cleaned (i.e., the % full value is reset to zero) at the selected interval. This option is useful for long model runs.

Hydrodynamic devices are available for any individual source area or as a drainage system control. The following figure is the input screen for the hydrodynamic device. Hydrodynamic devices are very similar to catchbasins except that they have additional bypass capabilities and lamella plates can be added for improved performance.



First Source Area Control Practice
Hydrodynamic Device Number 1
Land Use: Commercial 1
Source Area: Paved Parking 1

Hydrodynamic Control Device General Information - Enter for Both Single Chamber and Proprietary Devices

Total Source Area (ac)	22.000
Area Served by Device (ac)	22.00
Number of Devices	10
Device Density (units/ac)	0.455

Select | Critical Particle Size file name:
C:\Program Files\WinSLAMM\NURP.CPZ

☑ Model Hydrodynamic Device with Lamella Plates or Settling Tubes

Fraction of device area with plates or tubes	.7
Average tube diameter or distance between plates (ft)	.25
Number of plates or tubes a vertical line will intersect	3

For Device Cleaning, Select Either

Device Cleaning Dates

Device Cleaning No.	Device Cleaning Date (mm/dd/yy)
1	
2	
3	
4	
5	

OR

☐ Device Cleaning Frequency
○ Monthly
○ Three Times per Year
○ Semi-Annually
○ Annually
○ Every Two Years
○ Every Three Years
○ Every Four Years
○ Every Five Years
○ Never

Single Chamber Device Characteristics

1 - Average Sump Depth below Device Outlet Invert (ft)	6.00
Depth of Sediment in Device at Beginning of Study Period (ft)	0.00
2 - Typical Outlet Pipe Diameter (ft)	1.00
Typical Outlet Pipe Manning's n	0.013
3 - Typical Outlet Pipe Slope (ft/ft)	0.0100
Typical Device Sump Surface Area (sf)	50.0
4 - Device Depth from Sump Bottom to Street Level (ft)	8.00
Inflow Hydrograph Peak to Average Flow Ratio	3.8
5 - Minimum Allowable Scour Depth Below Outlet Invert (ft)	1.0
Maximum Flow to In-Line Sump (cfs)	0.50
6 - Diameter of Orifice that Controls Flow to In-Line Sump (ft)	N/A - Click to Activate
7 - Inflow Orifice Invert Elevation (ft)	N/A
8 - Length (ft) of Overflow Structure Acting as a Sharp-Crested Weir	N/A
9 - Elevation of Overflow Structure to Bypass In-Line Sump (ft above sump base)	N/A

☐ Or Use Proprietary Hydrodynamic Control Device Information

Manufacturer - Model

1 - Average Sump Depth below Device Outlet Invert (ft)	
Depth of Sediment in Device at Beginning of Study Period (ft)	
2 - Typical Outlet Pipe Diameter (ft)	
Typical Outlet Pipe Manning's n	
3 - Typical Outlet Pipe Slope (ft/ft)	
Inflow Hydrograph Peak to Average Flow Ratio	
5 - Minimum Allowable Scour Depth Below Outlet Invert (ft)	
Device Sump Surface Area (sf)	

Control Practice # : 4 | Land Use # : 2 | Source Area # : 13

Input screen for hydrodynamic device.

There are five sections to the hydrodynamic control device form. They are:

1. Hydrodynamic Device General Information. This includes the source area of the device, the area within the source area that is served by the device, the number of devices, the device density and the particle size file name (to define the particle size distribution of the runoff entering the device. This information is needed regardless of whether you are modeling a single chamber device or a proprietary device. If you have checked the 'Route Hydrographs and Particle Sizes Between Control Devices' box in Program Options/Default Model Options, then the program will use the default particle size distribution file for all source areas. The particle size distribution entering the control device will be modified by whatever practices are upstream of the control practice. If the practice is the most upstream practice, then the default particle size distribution is used.

You will also need to enter either the information necessary to characterize a single chamber device or a proprietary device. The single chamber device includes the same information that you would enter for a catchbasin with inflow bypass data. The proprietary device option will allow you to select a particular device manufacturer and model number, assuming the performance data for that device has been added to WinSLAMM.

2. Single Chamber Device Characteristics. If you are modeling a generic single chamber device, you must enter the following information.

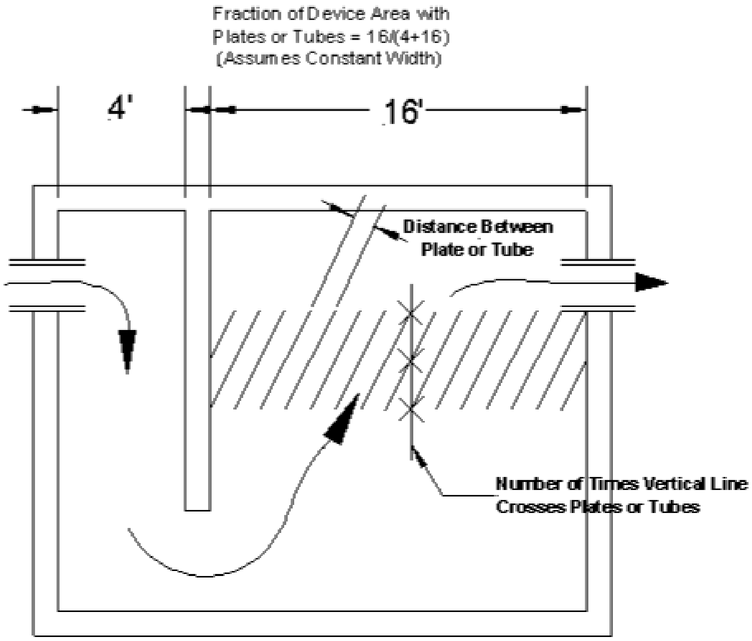
Average sump depth below hydrodynamic device outlet invert (feet)
Depth of sediment in hydrodynamic device sump at beginning of study period (ft)
Typical outlet pipe diameter (ft)
Typical outlet pipe Manning's n
Typical outlet pipe slope (ft/ft)
Typical hydrodynamic device sump surface area (square feet)
Total hydrodynamic device depth (feet)
Inflow hydrograph peak to average flow ratio
Maximum allowable depth of sediment below outlet invert elevation

For flow bypass,
Either: Maximum flow to inline sump (cfs)
Or: Diameter of orifice that controls flow to in-line sump (ft)
Inflow orifice invert elevation (ft)
Length (ft) of overflow structure acting as a sharp-crested Weir
Elevation of overflow structure to bypass inline sump (ft above sump base)

3. Proprietary Device. If you are modeling a proprietary device, check the 'Or Use Proprietary Hydrodynamic Control Device Information' checkbox and then use the pull down menu to select the device manufacturer and model number. Enter any other relevant information in the data grid.

4. Device Cleaning. You may enter in either specific cleaning dates or a cleaning frequency. If you select to model device cleaning, then when the date in the model run is reached during processing, the program will remove all stored sediment in the device.

5. Model Hydrodynamic Device with Lamella Plates or Settling Tubes. This option allows you to model the increased settling efficiency that occurs when the device uses lamella plates or settling tubes. When this option is selected, the program increases the effective surface area of the device by the number of plates or tubes that a vertical line will intersect. This occurs for each time step that the flow through the device is laminar. Laminar flow is assumed if the Reynolds number is less than 2100. The Reynolds number is determined from the water velocity through the tubes (and so varies with flow), the kinematic viscosity of the water, and the tube diameter or distance between lamella plates.

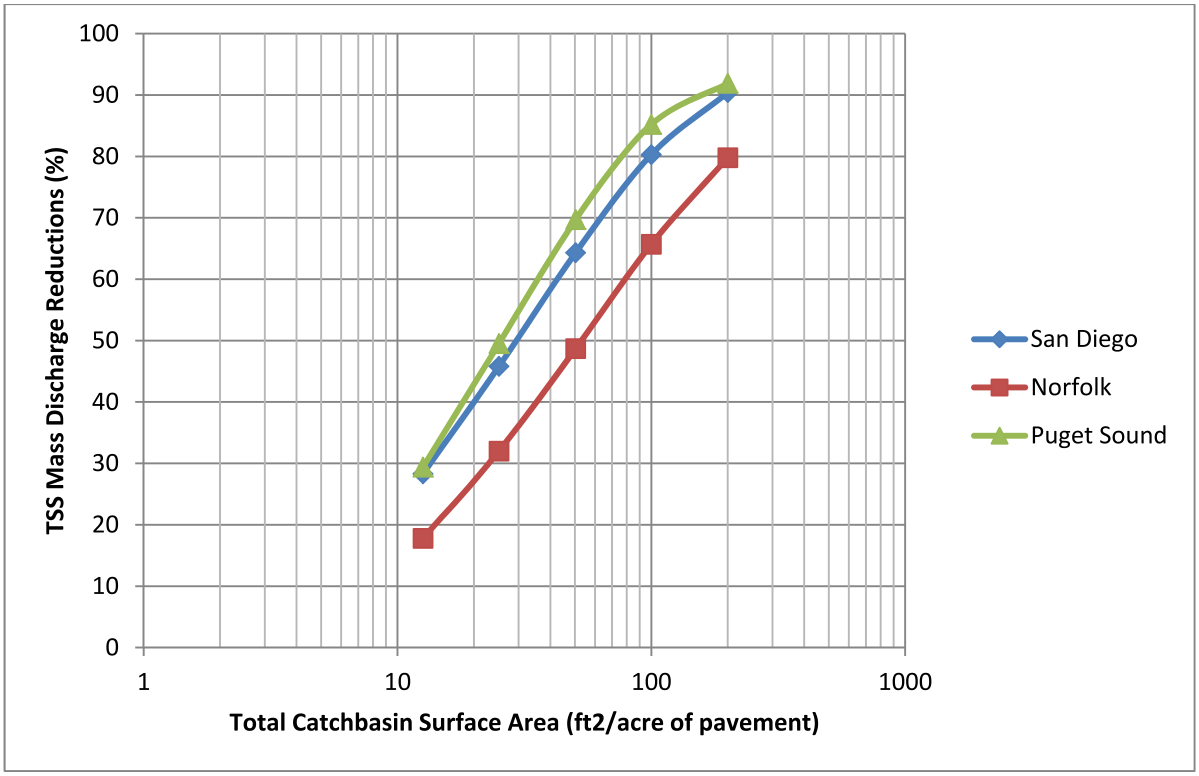


Lamella plates in a hydrodynamic device.

To model a hydrodynamic device with lamella plates or settling tubes, first check the box next to the lamella plate or settling tube label. Then enter:

1. The fraction of the total device surface area (0 - 1) with plates or tubes.
2. The average settling tube diameter or distance between lamella plates (ft)
3. The number of plates or tubes a vertical line will intersect.

The following figure is a production function for the use of catchbasins (or simple hydrodynamic devices) in a paved area. The main factor is the total surface area of the devices (expressed as ft^2 per acre of pavement). The model calculations were based on standard 4 ft diameter catchbasins (having 3 ft sumps below the outlet), and varying numbers of units were considered. This is generally equivalent to the combined surface areas, although specific calculations would be appropriate for further analyses. The San Diego and Puget Sound levels of performance are similar, while the higher flow rates associated with the Norfolk site reduced the performance for the same sized facilities. This plot is only for TSS mass discharge reductions as there are no runoff volume reductions associated with these devices. However, these can be used as part of treatment trains, especially to remove large debris to prevent fouling of other unit processes. It is difficult to obtain high levels of treatment with these devices unless they were very large (approaching the size of a wet detention pond, for example). In order to obtain 90% TSS reductions (not observed during field monitoring), about 200 ft^2 of sump area would be needed (or about 16 conventional catchbasins per acre, an impractical number). In order to obtain these larger removals, single large devices would be most suitable, or used in conjunction with other systems (as described later for the MCTT).



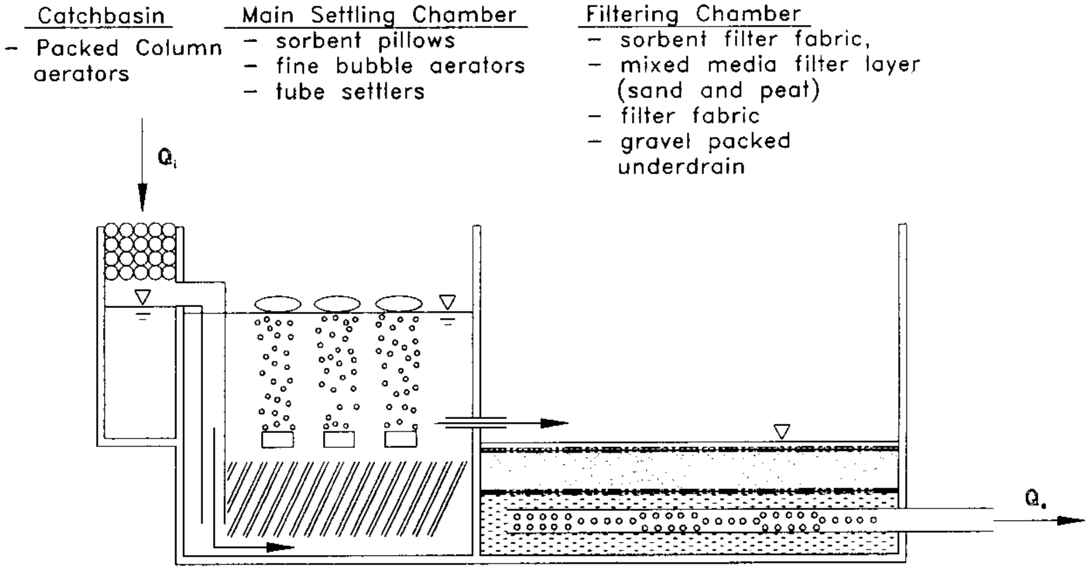
Multi-Chambered Treatment Train (MCTT)

The Multi-Chambered Treatment Train (MCTT) was developed to control toxicants in stormwater from critical source areas. The MCTT is most suitable for use at relatively small areas, about 0.1 to 1 ha in size, such as vehicle service facilities, convenience store parking areas, equipment storage and maintenance areas, and salvage yards, although it has been used in much larger areas. The MCTT is normally installed underground and is typically sized between 0.5 to 1.5 percent of the paved drainage area. It is comprised of three main sections, an inlet having a conventional catchbasin with litter traps, a main settling chamber having lamella plate separators and oil sorbent pillows, and a final chamber having a mixed sorbent media (usually peat moss and sand). During monitoring, the MCTT provided median reductions of >90% for toxicity, lead, zinc, and most organic toxicants. Suspended solids were reduced by more than 80% and COD was reduced by 60%. The information presented in this section is based on the results from a series of projects sponsored by the US EPA (Pitt, *et al.* 1996, Clark and Pitt 1999, Pitt, *et al*. 1999, and Clark 2000).

This study also confirmed that many toxicants are associated with particulate matter in runoff. Industrial/commercial areas are likely to be the most significant pollutant source areas, with the highest toxicant concentrations and most frequent occurrences found at vehicle service and parking/storage areas. The duration of the antecedent dry period before a storm and the intensity of the storm event were found to be significant factors influencing the concentrations of most of the toxicants detected. These critical areas were further evaluated during treatability tests. The treatability study found that settling, screening, and aeration and/or photo-degradation treatments showed the greatest potential for toxicant reductions, as measured by the reduction in toxicity of the samples, using the Microtox^{TM} toxicity screening test.

The main settling chamber provided substantial reductions in total and dissolved toxicity, lead, zinc, certain organic toxicants, SS, COD, turbidity, and color. The sand-peat chamber also provided additional filterable toxicant reductions. However, the catchbasin/grit chamber did not provide any significant improvements in water quality, although it is an important element in reducing maintenance problems by trapping bulk material. Zinc and toxicity are examples where the use of the final chamber was needed to provide high levels of control. Otherwise, it may be tempting to simplify the MCTT by removing the last chamber. Another option would be to remove the main settling chamber and only use the pre-treating capabilities of the catchbasin as a grit chamber before the peat "filtration" chamber (similar to many stormwater filter designs). This option is not recommended because of the short life that the filter would have before it would clog (Clark and Pitt 1999; Clark 2000). In addition, the bench-scale tests showed that a treatment train was needed to provide some redundancy because of frequent variability in sample treatability storm to storm, even for a single sampling site.

The following figure shows a cross section of the MCTT. The catchbasin functions primarily as a protector for the other two units by removing large, grit-sized material. The setting chamber is the primary treatment chamber for removing settleable solids and associated constituents. The sand-peat filter is for final polishing of the effluent, using a combination of sorption and ion exchange for the removal of soluble pollutants, for example.



MCTT cross section.

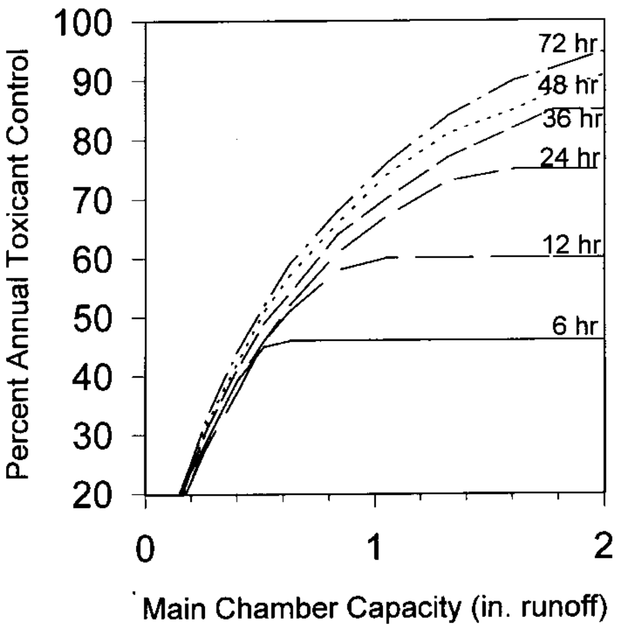
The main settling chamber mimics the completely mixed settling column bench-scale tests previously conducted and uses a hydraulic loading rate (depth to time ratio) for removal estimates. This loading rate is equivalent to the conventional surface overflow rate (SOR), or upflow velocity, for continuous-flow systems, or the ratio of water depth to detention time for static systems. The MCTT can be operated in both modes. If it uses an orifice, to control the settling chamber outflow, then it operates in a similar mode to a conventional wet detention pond and the rate is the upflow velocity (the instantaneous outflow divided by the surface area of the tank). If the outflow is controlled with a float switch and a pump, then it operates as a static system and the hydraulic loading rate is simply the tank depth divided by the settling time before the pump switches on to remove the settled water.

In addition to housing plate or tube settlers, the main settling chamber also contains floating sorbent "pillows" to trap floating oils and a fine bubble aerator that operates during the filling time of the MCTT. Plate settlers (or inclined tubes) increase solids removal by reducing the distance particles travel to the chamber floor and by reducing scour potential. The main settling chamber operates much like a settling tank, but with the plate settlers increasing the effective surface area of the tank. The increase in performance is based on the number of plate diagonals crossing the vertical. If the plates are relatively flat and close together, the increase in performance is greater than if the plates are steeper and wider apart. The effective increase is usually about 3 to 5 fold. The settling time in the main settling chamber typically ranges from 1 to 3 d, and the settling depth typically ranges from 0.6 to 2.7 m (2 to 9 ft). These depth to time ratios provide for excellent particulate (and associate pollutant) removals in the main settling chamber.

Depth/time ratios of at least 3 X 10^{-5} m/s (1 X 10^{-4} ft/s) are needed to obtain a median toxicity reduction of at least 70 percent in the main settling chamber. If the main settling chamber tank was one meter (3.3 ft) deep, then the required detention time would have to be at least 0.4 days to obtain this level of treatment. If the tank was twice as deep, the required detention time would be 0.8 days. The tank surface area is therefore based on the volume of runoff to be detained and the settling depth desired/available. Shallow tanks require shorter detention times than deeper tanks, but the surface areas are correspondingly larger, and scour may be more of a problem.

If the rains are infrequent, long detention periods are easily obtained without having "left-over" water in the tank at the beginning of the next event. However, if the rains are frequent, the available holding times are shortened, requiring shallower main settling chamber tanks for the same level of treatment. A spreadsheet model was used to develop design curves for many locations of the U.S. based on long-term rain records, desired levels of control, and tank geometry. This model was used to investigate various storage capacities, holding periods, and settling tank depths for 21 cities throughout the U.S. having annual rains from about 180 – 1500 mm (7 – 60 in.). The model used the rain depths and durations, the time interval between the consecutive storm events, the dimensions of the subsurface tank, and the tank pumpout or drainage time.

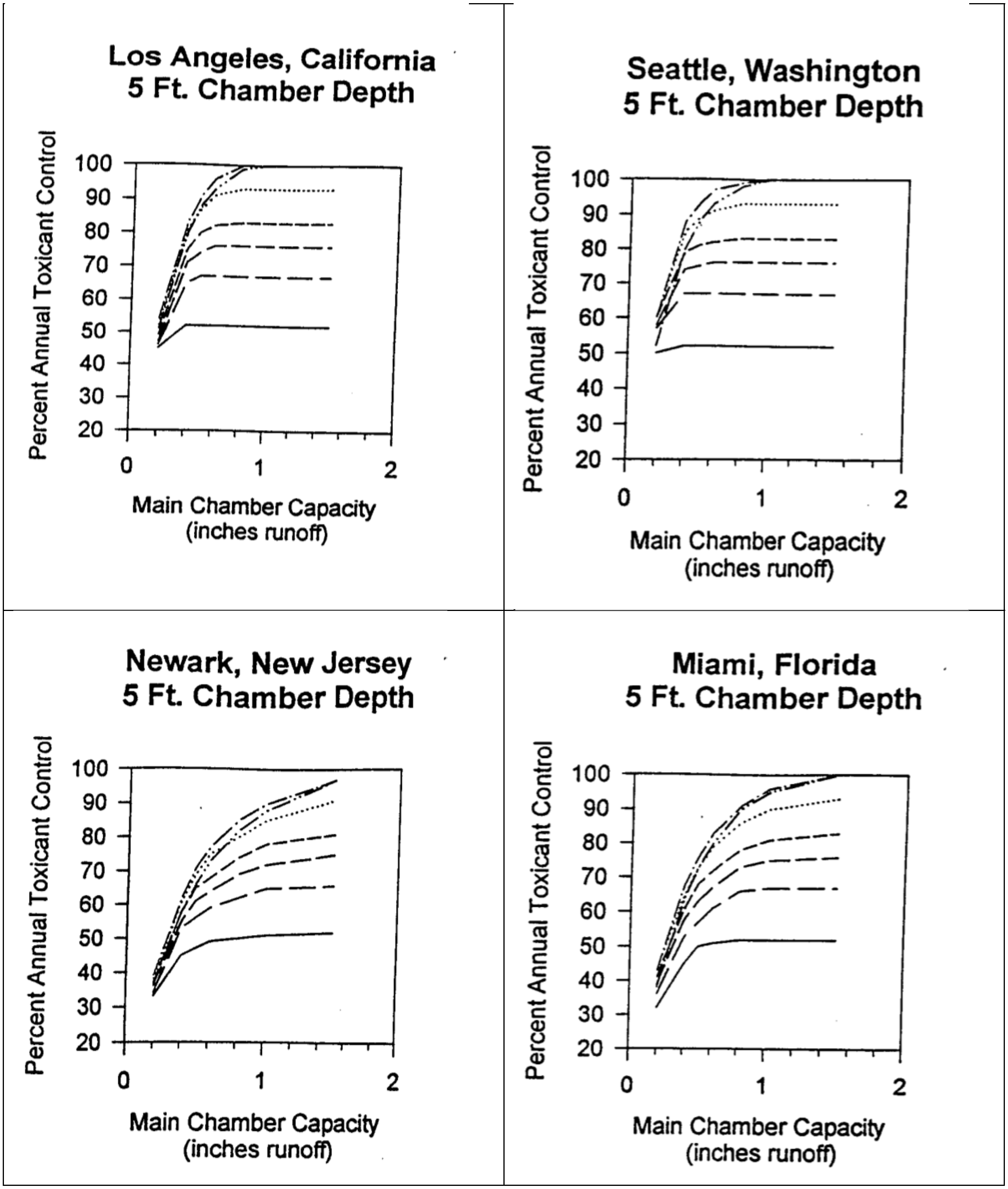
The following figure is the plot for Birmingham, AL, for different annual control levels associated with holding periods from 6 – 72 h and storage volumes from 2.5 – 51 mm (0.1 – 2.0 in.) of runoff for a 2.1 m (7 ft) deep MCTT. This figure can be used to determine the size of the main settling chamber and the minimum required detention time to obtain a desired level of control (toxicity reduction). Birmingham, AL, rains typically occur about every 3 to 5 d, so it would be desirable to have the holding period less than this value. Similarly, if the storage volume was small, only a small fraction of a large rain would be captured and treated, requiring a partial bypass for most rains.



Effects of storage volume and treatment time on annual toxicity reduction, 2.1 m settling depth) (Example storage-treatment plot for Birmingham, AL).

This plot shows that the most effective holding time and storage volume for a 70% toxicity reduction goal is 72 hours and 22 mm (0.86 inch) of runoff storage. A shorter holding period would require a larger holding tank for the same level of control. Shorter holding periods may only be more cost-effective for small removal goals (<50%). If a 6 hour holding time was used, the maximum toxicant removal would only be about 46% for this tank depth.

The following figure shows similar MCTT design curves for coastal areas near naval facilities. For 70% toxicity reductions, the 72 hr holding period is recommended, with 0.30 in storage for Southern California, 0.25 in storage for Puget Sound, and 0.42 to 0.50 in storage for east coast areas. These storage volumes are also all for 5 ft depths over the standing water elevation (such as over the lamella plates), resulting in tank heights of about 7 ft. The following table summarizes some of these tank dimensions.



Los Angeles, California
5 Ft. Chamber Depth

Seattle, Washington
5 Ft. Chamber Depth

Newark, New Jersey
5 Ft. Chamber Depth

Miami, Florida
5 Ft. Chamber Depth

MCTT main settling chamber design curves for U.S. coastal areas near naval facilities.

MCTT Main Settling Chamber Dimensions to Provide 70% Toxicity Reductions

Location	Holding period (hrs)	Storage volume above lamella plates (standing water) (watershed inches)	Runoff volume for one acre pavement (ft^3)	Tank surface area for 5 ft of storage depth (ft^2)	Settling tank area as a percentage of pavement area (%)
Los Angeles	72	0.30	1089	218	0.50
Seattle	72	0.25	908	182	0.42
Newark	72	0.50	1815	363	0.83
Miami	72	0.42	1524	305	0.70

The final MCTT chamber is a mixed media filter (sorption/ion exchange) device. It receives water previously treated by the grit and the main settling chambers. The initial designs used a 50/50 mix of sand and peat moss, while some used a 33/33/33 mixture of sand, peat moss, and granulated activated carbon. The MCTT can be easily modified to contain any mixture of media in the last chamber. However, care must be taken to ensure an adequate hydraulic capacity. As an example, peat moss alone was not effective because it compressed quickly, preventing water from flowing through the media. However, when mixed with sand, the hydraulic capacity was much greater and didn't change rapidly with time. Bench-scale tests show that sand by itself (especially if recently installed) does not permanently retain the stormwater toxicants (which are mostly associated with very fine particles and which were mostly washed from the sand during later events). This lack of ability to permanently retain stormwater toxicants prompted the investigation of other filtration media. The sand-peat filter possesses ion exchange, adsorption, and filtration reduction mechanisms. As the media ages, the performance of these processes will change. Ion exchange capacity and adsorption sites, primarily associated with the peat moss, will be depleted. Filtration, primarily associated with the sand, however, is expected to increase, especially for the trapping of smaller particles. Replacement of the media in an MCTT is expected to be necessary about every 3 to 5 years.

The following table shows example sizing calculations for the ion exchange/sorption chamber that receives flow from the main settling chamber (flow controlled by a very small orifice, a recommended SmartDrain, or a small pump). The filter chamber areas are about 56% of the main settling tank area (based on the 5 ft settling/storage depth in the main settling tank). The media flow rate is typically selected corresponding to a slow sand filter rate of about 3 ft/day.

MCTT Ion Exchange/Sorption Chamber Dimensions to Match Main Settling Tank Size

Location	Runoff volume for one acre pavement (ft^3)	Holding period (hrs)	Discharge rate from settling chamber (CFS, gpm)	Filter surface area for 3 ft/day filtering rate (ft^2)	Filter tank area as a percentage of pavement area (%)
Los Angeles	1089	72	0.0042 (1.6)	121	0.28
Seattle	908	72	0.0035 (1.3)	101	0.23
Newark	1815	72	0.0070 (2.7)	202	0.46
Miami	1524	72	0.0059 (2.2)	170	0.39

As an example, a complete MCTT for a one acre paved area in the San Diego area (using the Los Angeles sizing information) therefore includes a standard 4 ft diameter catchbasin with a sump and debris screening, followed by a main settling chamber of 218 ft^2 and a filter chamber of 121 ft^2, for a total footprint area of about 350 ft^2, or 0.8% of the paved area. The largest MCTT in the New York area would be about 1.6 times the area of the San Diego system (1.3% of the paved drainage area).

Selection of Media for Treatment Devices

Pitt and Clark (2010) reviewed many media available for the removal of heavy metals and organics to very low levels. Critical aspects of these advanced treatment methods include using sufficient pre-treatment for the removal of fine particulates to minimize silting of the treatment media and also to provide sufficient contact time of the water being treated with the media.

Clark and Pitt (2011) found that zeolites can be effective for removal of metals in the +2 valence state. The effectiveness of ion exchange decreases as the valence charge approaches zero and as the size of the complex increases. Therefore, the overall effectiveness of zeolites, and potentially other ion-exchange media such as oxide-coated sands, is likely reduced because a substantial fraction of the metals likely exist in valence forms other than +2 due to complexation with inorganic ions and organic matter.

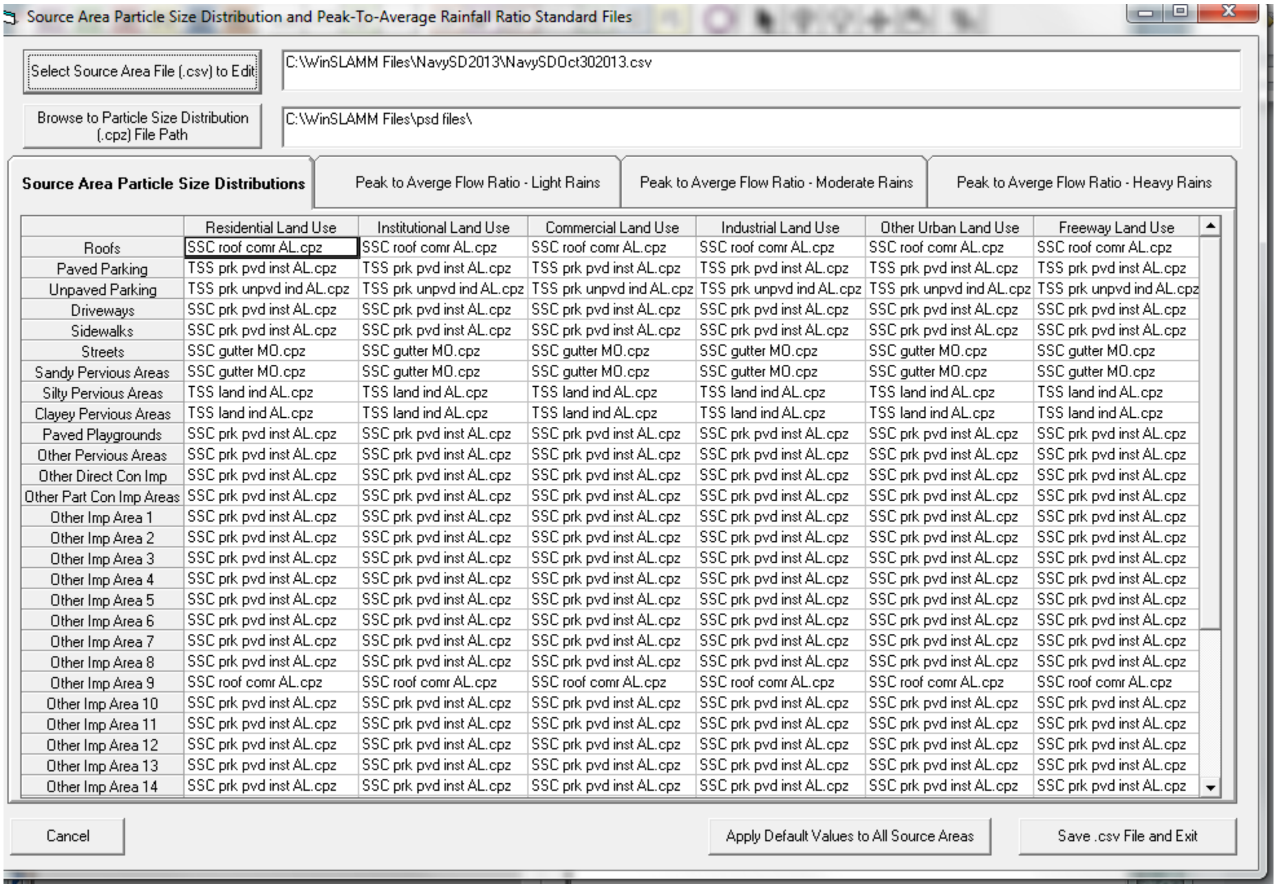
Organic compounds and larger, less charged complexes of metals, can be chemically bonded with a media having strong sorption capacities. K_{OW} is an indication of the preference for the molecule to attach to an organic media (peat, compost, GAC) versus remaining in the stormwater runoff. K_S indicates the likelihood that the organic compound will remain dissolved in solution. The removal of some inorganic anions is difficult because most stormwater treatment media specifications stress high cation exchange capacities (CEC). High CEC media typically have low anion exchange capacities (AEC). CEC and AEC provide an estimate of the potential for exchanging a less-desirable compound with a pollutant whose chemical characteristics are more favorable. The following table lists some of the organic and metallic pollutants of concern in stormwater runoff and potential treatment options, based on their chemical properties and the results of laboratory, pilot-scale, and full-scale treatment tests.

Selecting Treatment Technologies for Stormwater Organic and Metallic Pollutants (summarized from Clark and Pitt 2012)

Organics and Pesticides		
PAHs/Oil and Grease (O&G)/Dioxin	Sedimentation or filtration, possibly followed with chemically-active media.	These compounds have high K_{OW} and low K_S and are strongly associated with particulates. Sedimentation's effectiveness is function of particle size association. Preferential sorption to organic media, such as peat, compost, and soil. Some O&G components can be microbially degraded in filter media. Reductions to very low levels with filtration may be difficult if parent material is contaminated. If low numeric permit limits exist, may have to use clean manufactured material, such as GAC.
Organic Acids and Bases	Chemically-active filtration	Tend to be more soluble in water than PAHs and more likely to be transported easily in treatment media. Need media with multiple types of sorption sites, such as peat, compost and soil. GAC possible if nonpolar part of molecule interacts well with GAC or if GAC has stronger surface active reactions than just van der Waals strength forces.
Pesticides	Chemically-active filtration	Tend to be soluble in water and need multiple reaction sites to be removed. Breakdown time in biologically-active filtration media is compound-dependent. Breakdown has the potential to restore surface-active sites, and may result in more soluble daughter products, which may or may not be more toxic. Organic media such as peat, compost, soil, GAC likely to be most effective since size of pesticide compounds will exclude substantial removal in ion-exchange resins such as zeolites.
Lead	Ion-exchange Chemically-active media filtration	Lead attaches strongly to solids. Substantial removal by sedimentation and/or physical filtration of solids to which lead is attached. • Lead < 0.45 mm may be ionic and could be removed using ion-exchange with zeolites, but filtered, ionic lead is usually at very low concentrations and it would be unusual to require treatment. • Lead complexes with hydroxides and chlorides to a certain extent. Removed in media with variety of binding sites (peat, compost, soil).
Copper, Zinc, Cadmium	Chemically-active filtration	These metals can attach to very small particles, with attachments being a function of the particulate organic content, pH, and oxidation-reduction conditions (filterable fractions vary from 25 to 75+%). Physical filtration may be limited depending on size association of the pollutants. These metals complex with a variety of organic and inorganic ligands to create soluble complexes of varying valence charges (-2 to +2). Small amount of ionic species (metal as +2 ion only) reduces ion-exchange effectiveness. Complexes require variety types of sorption/exchange sites. Organic complexes may be removed by GAC. Peat, compost and soil will remove most inorganic and organic complexes. Concern about contamination of media with captured metals.

Appendix A: Particle Size Distributions for Source Areas

WinSLAMM now has the capability of tracking particle size distributions from source areas through the drainage systems and control practices. This requires the selection of the *.psd file for each source area and land use. In WinSLAMM version 10.1, these are entered as part of the “Source Area Particle Size Distribution and Peak-to-Average Rainfall Ratio Standard Files” screen (under the tools\edit source are default variables drop down menu), as shown below in an example file. As shown in this example, different *.cpz (critical particle size) files can be selected for each source area in each land use. If preferred, the same *.cpz file can be used for all source areas for all land uses also.



C:\WinSLAMM Files\NavySD2013\NavySDOct302013.csv

C:\WinSLAMM Files\psd files\

	Residential Land Use	Institutional Land Use	Commercial Land Use	Industrial Land Use	Other Urban Land Use	Freeway Land Use
Roofs	SSC roof comr AL.cpz	SSC roof comr AL.cpz	SSC roof comr AL.cpz	SSC roof comr AL.cpz	SSC roof comr AL.cpz	SSC roof comr AL.cpz
Paved Parking	TSS prk pvd inst AL.cpz	TSS prk pvd inst AL.cpz	TSS prk pvd inst AL.cpz	TSS prk pvd inst AL.cpz	TSS prk pvd inst AL.cpz	TSS prk pvd inst AL.cpz
Unpaved Parking	TSS prk unpvd ind AL.cpz	TSS prk unpvd ind AL.cpz	TSS prk unpvd ind AL.cpz	TSS prk unpvd ind AL.cpz	TSS prk unpvd ind AL.cpz	TSS prk unpvd ind AL.cpz
Driveways	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz
Sidewalks	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz
Streets	SSC gutter MO.cpz	SSC gutter MO.cpz	SSC gutter MO.cpz	SSC gutter MO.cpz	SSC gutter MO.cpz	SSC gutter MO.cpz
Sandy Pervious Areas	SSC gutter MO.cpz	SSC gutter MO.cpz	SSC gutter MO.cpz	SSC gutter MO.cpz	SSC gutter MO.cpz	SSC gutter MO.cpz
Silty Pervious Areas	TSS land ind AL.cpz	TSS land ind AL.cpz	TSS land ind AL.cpz	TSS land ind AL.cpz	TSS land ind AL.cpz	TSS land ind AL.cpz
Clayey Pervious Areas	TSS land ind AL.cpz	TSS land ind AL.cpz	TSS land ind AL.cpz	TSS land ind AL.cpz	TSS land ind AL.cpz	TSS land ind AL.cpz
Paved Playgrounds	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz
Other Pervious Areas	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz
Other Direct Con Imp	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz
Other Part Con Imp Areas	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz
Other Imp Area 1	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz
Other Imp Area 2	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz
Other Imp Area 3	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz
Other Imp Area 4	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz
Other Imp Area 5	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz
Other Imp Area 6	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz
Other Imp Area 7	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz
Other Imp Area 8	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz
Other Imp Area 9	SSC roof comr AL.cpz	SSC roof comr AL.cpz	SSC roof comr AL.cpz	SSC roof comr AL.cpz	SSC roof comr AL.cpz	SSC roof comr AL.cpz
Other Imp Area 10	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz
Other Imp Area 11	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz
Other Imp Area 12	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz
Other Imp Area 13	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz
Other Imp Area 14	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz	SSC prk pvd inst AL.cpz

Several particle size distribution files are distributed with WinSLAMM, mostly based on extensive monitoring, as shown on Table 1 show the older particle size files, along with files created from recent research conducted by Pitt and his research group. These samples were all collected using completed mixed conditions and represent wide particle size ranges.

Table 1. Particle Size Distribution Files Included with WinSLAMM (percentage of sample, by mass, greater than size indicated)

size (µm)	Const. sites – Tusc (AL)	roof runoff - Tusc (AL)	parking lot BamaBelle (AL)	gutter KC curb cuts (MO)	open space SSFL (CA)	outfall NURP	outfall Midwest	outfall Monroe	Low	Medium	High
1	100	100	92	100	100	98	100	84	96	99	100
3	99	94	88	100	93	77	93	64	65	90	98
5	95	90	81	97	89	65	89	56	54	82	94
10	92	84	72	89	78	44	78	46	25	67	87
30	43	65	59	49	53	22	53	24	9	42	69
50	33	42	51	36	42	16	42	21	6	31	56
100	25	28	41	26	28	9	28	17	2	19	40
300	15	18	10	15	12	3	12	12	0	8	19
500	8	15	5	10	7	1	7	8	0	5	11
1000	1	8	1	4	3	0	3	4	0	2	5
2000	0	0	0	0	0	0	0	2	0	0	0
Median (µm):	27	43	53	30	35	9	35	8	7	24	59

The file names for these particle size distributions are:

SSC cnstrcn AL (Construction sites in Tuscaloosa)
SSC roof comr AL (Roof runoff at commercial sites in Tuscaloosa)
SSC park pvd instit AL (Parking lot in park adjacent to BamaBelle)
SSC gutter MO (Gutter flows entering curb cut biofilters in Kansas City)
SSC opn spc CA (Open space at SSFL in LA County)
TSS otfl NURP (outfall samples from all of the NURP sites doing PSD analyses)
TSS otfl Mdwst IL MI (outfall samples from the NURP sites in IL and MI)
SSC otfl Mnro WI (outfall samples from the Monroe St monitoring location in Madison, WI)
TSS otfl low (outfall samples representing low sediment concentrations)
TSS otfl medium (outfall samples representing typical sediment concentrations)
TSS otfl high (outfall samples representing high sediment concentrations)

These files are further described below:

Low, medium, and high cpz files: the work by Grizzard and Randall (1986) at east coast sites indicated significantly different particle size distributions for stormwaters from the same site having different suspended solids concentrations. The highest suspended solids concentrations were associated with waters having relatively few small particles, while the low suspended solids concentration waters had few large particles.

Outfall NURP, Midwest cpz files: These data are from outfall samples collected from a number of NURP (Nationwide Urban Runoff Study) locations and from just those in the Midwest. The analyses were conducted by gravimetric settling columns by the USGS. The upper Midwest data sources were from two of the NURP projects: Terstriep, *et al*. (1982), in Champaign/Urbana, IL, and Akeley (1980) in Washtenaw County, Michigan.

Outfall Monroe cpz file: These data are from the inlet to the Monroe St. wet detention pond in Madison, WI. The samples were collected using automatic samplers and from bedload samplers (results integrated) over a period of about three years. The PSDs were analyzed by the USGS.

Open space SSFL cpz file: These data represent grab samples collected on the Santa Susana Field Laboratory site in Ventura County, CA. The samples were obtained in rugged semi-arid open space areas. The samples were collected over a two year period and were analyzed using a laser particle size analyzer.

Gutter KC curb cut cpz file: These data represent averaged results from the gutter flow samples obtained using automatic samplers at curb cuts at the inlets to biofilters in the Kansas City green infrastructure demonstration project area, collected over a three year period. These samples were analyzed for particle size distributions using a combination of multiple sieve analyses plus Coulter Counter analyses.

Parking lot BamaBelle cpz file: Parking lot samples were collected using an automatic sampler, along with bed load from the sump of the Upflow Filter that was being evaluated. The site was at a parking lot for a river front park that has moderate parking, along with some landscaping runoff contributions from the areas surrounding the parking lot. Thirty samples were collected over a one year period and this represents an overall average PSD. These samples were analyzed for particle size distributions using a combination of multiple sieve analyses plus Coulter Counter analyses, and the sump samples were also integrated into the finer fraction data.

Roof runoff Tuscaloosa cpz file: Roof runoff samples were collected (manual grab samples) as part of Renee Morquecho's dissertation research at UA on stormwater treatability. She was focusing on the metal associations (and their characteristics) as a function of particle size from several source areas. The other sampling locations were for mixed flows. These samples were analyzed for particle size distributions using a combination of multiple sieve analyses plus Coulter Counter analyses.

Construction sites Tuscaloosa cpz file: Grab samples from about 12 construction sites in the Tuscaloosa, AL, area were collected in 2012 as part of a class project to determine the level of treatment (defined by critical particle size) to meet various turbidity numeric effluent limits being proposed for construction site runoff. These samples were analyzed using a combination of multiple sieve analyses plus Coulter Counter analyses.

Table 2 shows particle size distributions from grab sheetflow samples collected during research examining treatability of stormwater and the development of the Multi-Chambered Treatment Train (Pitt, R., B. Robertson, P. Barron, A. Ayyoubi, and S. Clark. *Stormwater Treatment at Critical Areas: The Multi-Chambered Treatment Train (MCTT)*. U.S. Environmental Protection Agency, Wet Weather Flow Management Program, National Risk Management Research Laboratory. EPA/600/R-99/017. Cincinnati, Ohio. 505 pgs. March 1999). These samples were obtained from sheetflows during rains using a vacuum sample bottle and Teflon tube. The samples were analyzed using an early model laser particle counter. It was apparent that this instrument did not detect particles larger than about 75 um, usually considered the upper limit of particles for TSS (SSC covers the complete particle size range). Therefore, these data should only be applied to a modeling situation where the particulate solids calibration and verification relied on TSS data. Similarly, using PSD data from SSC samples with TSS calibrations would artificially increase the importance of the larger particles, resulting in increased (in error) particulate capture calculations.

Table 2. Particle Size Distributions from Source Area Grab Samples Collected in the Birmingham, AL, Area (for TSS)

particle size	roof resid	roof commer	roof indus	paved park resid	paved park commer	paved park instit	unpvd park indus
1	100	100	100	100	100	100	100
3	100	100	100	100	100	100	100
5	100	98	100	100	100	100	100
10	100	85	88	100	100	100	100
30	21	45	15	73	70	15	95
50	6	24	4	13	20	0	0
100	0	0	0	0	0	0	0
300	0	0	0	0	0	0	0
500	0	0	0	0	0	0	0
1000	0	0	0	0	0	0	0
2000	0	0	0	0	0	0	0
median	22	27	14	35	35	19	43
TSS (mg/L)	27	4	5	16	43	104	170

Table 2. Particle Size Distributions from Source Area Grab Samples Collected in the Birmingham, AL, Area (for TSS) (continued)

particle size	unpvd park instit	paved storage commer	paved storage indus	unpaved storage indus	street runoff resid	street runoff instit
1	100	100	100	100	100	100
3	100	100	100	100	100	100
5	100	100	100	100	100	100
10	100	100	100	100	100	100
30	84	48	93	2	60	46
50	0	19	32	0	26	28
100	0	0	0	0	0	3
300	0	0	0	0	0	0
500	0	0	0	0	0	0
1000	0	0	0	0	0	0
2000	0	0	0	0	0	0
median	50	29	46	24	34	26
TSS (mg/L)	32	12	21	152	7	22

Table 2. Particle Size Distributions from Source Area Grab Samples Collected in the Birmingham, AL, Area (for TSS) (continued)

particle size	street runoff indus	loading docks indus	vehicle service areas commer	landscaped runoff instit	landscaped runoff resid	landscaped runoff indus	CSO Brooklyn
1	100	100	100	100	100	100	100
3	100	100	100	100	100	100	100
5	100	100	100	100	100	100	100
10	100	100	100	100	100	90	100
30	26	55	71	82	50	34	97
50	0	18	19	3	10	0	45
100	0	0	0	0	0	0	0
300	0	0	0	0	0	0	0
500	0	0	0	0	0	0	0
1000	0	0	0	0	0	0	0
2000	0	0	0	0	0	0	0
median	27	32	37	35	50	21	49
TSS (mg/L)	66	40	24	12	10	41	94

The file names for these particle size distributions are:

TSS roofs res AL (residential area roof runoff samples from Birmingham)
TSS roofs comr AL (commercial area roof runoff samples from Birmingham)
TSS roofs ind AL (industrial area roof runoff samples from Birmingham)
TSS prk pvd res AL (residential paved parking area runoff samples from Birmingham)
TSS prk pvd comr AL (commercial paved parking area runoff samples from Birmingham)
TSS prk pvd inst AL (institutional paved parking area runoff samples from Birmingham)
TSS prk unpvd ind AL (industrial unpaved parking area runoff samples from Birmingham)
TSS prk unpvd inst AL (industrial unpaved parking area runoff samples from Birmingham)
TSS strg pvd comr AL (commercial paved storage area runoff samples from Birmingham)
TSS strg pvd ind AL (industrial paved storage area runoff samples from Birmingham)
TSS strg unpvd ind AL (industrial unpaved storage area runoff samples from Birmingham)
TSS strt res AL (residential street runoff samples from Birmingham)
TSS strt inst AL (institutional street runoff samples from Birmingham)
TSS strt ind AL (industrial street runoff samples from Birmingham)
TSS vhcl servc comr AL (vehicle service area in commercial area runoff samples from Birmingham)
TSS land inst AL (institutional area landscaped area runoff samples from Birmingham)
TSS land res AL (residential area landscaped area runoff samples from Birmingham)
TSS land ind AL (industrial area landscaped area runoff samples from Birmingham)
TSS CSO NY (combined sewage at overflow locations in Brooklyn, New York City)

Table 3 shows the particle size distributions associated with samples from several monitoring locations in the Madison, WI, area collected by the USGS (William R. Selbig, *Urban Water Journal* (2013): *Characterizing the distribution of particles in urban stormwater: advancements through improved sampling technology*). These data are unique in that the samples were collected using a new sampler intake that more accurately collects water from the complete depth of flow during a rain event, minimizing stratification issues associated with single point sampling, and represent SSC conditions. As noted above, these distributions should not be used with a model that has been calibrated using TSS data. These sample particle size distributions were determined using sieving methods for the large particles and a Coulter Counter for the smaller sized particles.

Table 3. Particle Size Distributions Included with WinSLAMM from Madison, WI, Monitoring (percentage of sample, by mass, greater than size indicated)

size (µm)	Residential feeder street - Madison	Residential arterial street - Madison	Residential collector street - Madison	Residential mixed flows - Madison	Commercial parking lot - Madison	Mixed land use outfall - Madison	Institutional roof runoff - Madison
1	100	87	95	100	90	94	95
3	82	79	68	81	73	88	85
5	79	75	56	77	69	86	82
10	70	67	43	70	60	84	78
30	62	58	34	68	51	82	76
50	50	47	27	52	32	72	68
100	34	27	15	39	17	48	49
300	16	9	5	16	5	19	20
500	11	5	3	12	3	12	10
1000	6	1	1	7	1	8	0
2000	2	0	0	2	0	3	0
median:	50	43	8	80	32	95	95
SSC (mg/L):	89	79	121	110	25	65	20

The file names for these particle size distributions are:

SSC strt fed res WI (residential area feeder street runoff samples from Madison, WI)
SSC strt art res WI (residential area arterial street runoff samples from Madison, WI)
SSC strt col res WI (residential area collector street runoff samples from Madison, WI)
SSC mxd resid WI (mixed flows from residential areas in Madison, WI)
SSC prk pvd comr WI (commercial area paved parking lot runoff from Madison, WI)
SSC otfl mxd WI (mixed land use outfall samples from Madison, WI)
SSC roof inst WI (institutional area roof runoff samples from Madison, WI)

These files are further described below:

Roof cpz file: downspout mixed samples before flows entered rain gardens at Madison area USGS office building. SSC median was 20 mg/L.

Street cpz files (collector, feeder, and arterial): Two arterial streets (40,000 and 49,450 vehicles/day), one collector street (6,600 vehicles/day) and two feeder streets (1,500 and 1,700 vehicles/day) were monitored in residential areas for 12 to 29 events. The streets had monthly street cleaning. The median SSC concentrations ranged from about 90 to 120 mg/L.

Mixed residential flow cpz file: 19 events were monitored in a section of the drainage system before the outfall, representing a mixture of residential source areas. The median SSC concentration was 110 mg/L at this location.

Parking lot cpz file: 22 events were monitored at a commercial parking lot. The median SSC concentration at this location was only 25 mg/L.

Outfall from mixed land use cpz file: 10 events were monitored at this mixed land use outfall location. The median SSC concentration was 65 mg/L at this location.

The *.cpz files described above can be used to represent a number of source areas in WinSLAMM, such as:

	TSS data	SSC data
Roofs	TSS roofs res AL TSS roofs comr AL TSS roofs ind AL	SSC roof comr AL SSC roof inst WI
Parking lots - paved	TSS prk pvd res AL TSS prk pvd comr AL TSS prk pvd inst AL	SSC prk pvd instit AL SSC prk pvd comr WI
Parking lots - unpaved	TSS prk unpvd ind AL TSS prk unpvd inst AL	
Storage areas - paved	TSS strg pvd comr AL TSS strg pvd ind AL	
Storage areas - unpaved	TSS strg unpvd ind AL	
Streets	TSS strt res AL TSS strt inst AL TSS strt ind AL	SSC gutter MO SSC strt fed res WI SSC strt art res WI SSC strt col res WI
Landscaped areas	TSS land inst AL TSS land res AL TSS land ind AL	
Open space areas		SSC opn spc CA
Vehicle service areas	TSS vhcl servc comr AL	
Combined sewer overflows	TSS CSO NY	
Construction sites		SSC cnstrcn AL
Mixed flows		SSC mxd resid WI
Outfalls	TSS otfl NURP TSS otfl Mdwst IL MI TSS otfl low TSS otfl medium TSS otfl high	SSC otfl Mnro WI SSC otfl mxd WI

Appendix B: Soil Compaction Effects on Infiltration Rates

Destruction of soil structure (specifically compaction) has been identified as a major cause of decreased infiltration rates in urban areas. All soils suffer when compacted, although compacted sandy soils still retain significant infiltration after compaction (but much less than if not compacted), while soils with substantial fines (especially clays) are more easily compacted to almost impervious conditions.

WinSLAMM therefore allows a selection of the compaction conditions for sandy, silty, and clayey soils. The model then uses the user defined infiltration rate reduction factor to represent the decreased infiltration rate of the soils. This option is only available for source area soil and landscaped conditions (and areas that receive runoff from disconnected impervious areas). Biofilter media compaction conditions should be reflected in the infiltration rates selected (the built-in biofilter infiltration rate values are based on measured values and already reflect typical conditions, but can be changed as warranted).

Field Tests of Infiltration Rates in Disturbed Urban Soils

A series of 153 double ring infiltrometer tests were conducted in disturbed urban soils in the Birmingham, and Mobile, Alabama, US, areas as part of an EPA project that investigated disturbed urban soils and soil amendments (Pitt, R., J. Lantrip, R. Harrison, C. Henry, and D. Hue. *Infiltration through Disturbed Urban Soils and Compost-Amended Soil Effects on Runoff Quality and Quantity*. U.S. Environmental Protection Agency, Water Supply and Water Resources Division, National Risk Management Research Laboratory. EPA 600/R-00/016. Cincinnati, Ohio. 231 pgs. December 1999, available at: http://www.unix.eng.ua.edu/~rpitt/Publications/BooksandReports/Compacted%20and%20compost%20amended%20soil%20EPA%20report.pdf). The tests were organized in a complete 2^3 factorial design to examine the effects of soil-water, soil texture, and soil density (compaction) on water infiltration through historically disturbed urban soils. Ten sites were selected representing a variety of desired conditions (compaction and texture) and numerous tests were conducted at each test site area. Soil-water content and soil texture conditions were determined by standard laboratory soil analyses. Compaction was measured in the field using a cone penetrometer and confirmed by the site history. During more recent tests, compaction is directly measured by obtaining samples from the field from a known volume (digging a small hole and retrieving all of the soil into sealed bags that are brought to the lab for moisture and weight analyses. The hole that is carefully cleaned of all loose soil is then filled with free-flowing sand from a graduated cylinder to determine the volume. The laboratory dry weight of the excavated soil is divided by the volume of the hole to obtain the density). From 12 to 27 replicate tests were conducted in each of the eight experimental categories in order to measure the variations within each category for comparison to the variation between the categories.

Soil infiltration capacity was expected to be related to the time since the soil was disturbed by construction or grading operations (turf age). In most new developments, compacted soils are expected to be dominant, with reduced infiltration compared to pre-construction conditions. In older areas, the soil may have recovered some of its infiltration capacity due to root structure development and from soil insects and other digging animals. Soils having a variety of times since development, ranging from current developments to those about 50 years old, were included in the sampling program. These test sites did not adequately represent a wide range of age conditions for each test condition, so the effects of age could not be directly determined. Other analyses have indicated that several decades may be necessary before compacted loam soils recover to conditions similar to pre-development conditions, if not continually compacted by site activities (such as parked cars on turf, unpaved walkways and parking lots, unpaved storage areas, or playing fields).

Figures 1 and 2 are 3D plots of this field infiltration data, illustrating the effects of soil-water content and compaction, for both sands and clays. Four general conditions were observed to be statistically unique. Compaction has the greatest effect on infiltration rates in sandy soils, with little detrimental effects associated with higher soil-water content conditions (the factor usually considered by most rainfall-runoff models). Clay soils, however, are affected by both compaction and soil-water content. Compaction was seen to have about the same effect as saturation on clayey soils, with saturated and compacted clayey soils having very little effective infiltration.

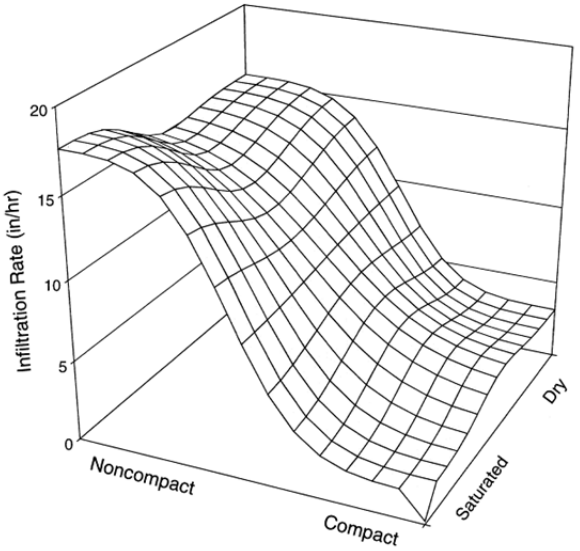


Figure 1. Three dimensional plot of infiltration rates for sandy soil conditions.

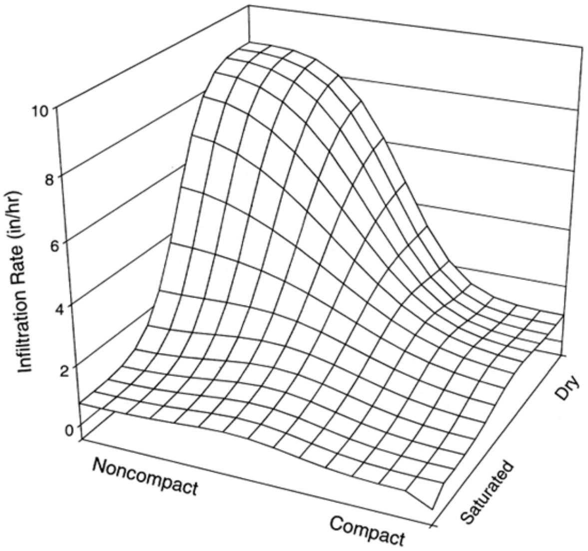


Figure 2. Three dimensional plot of infiltration rates for clayey soil conditions.

Laboratory Controlled Compaction Infiltration Tests

We use three levels of compaction to modify the density of soil samples during controlled laboratory tests: hand compaction, Standard Proctor Compaction, and Modified Proctor Compaction. Both Standard and Modified Proctor Compactions follow ASTM standard (D 1140-54). The Standard Proctor compaction hammer is 24.4 kN and has a drop height of 300 mm. The Modified Proctor hammer is 44.5 kN and has a drop height of 460 mm. For the Standard Proctor setup, the hammer is dropped on the test soil 25 times on each of three soil layers, while for the Modified Proctor test, the heavier hammer was also dropped 25 times, but on each of five soil layers. The Modified Proctor test therefore results in much more compacted soil, and usually reflects the most compacted soil usually observed in the field. The hand compaction is done by gentle hand pressing to force the soil into the test cylinder with as little compaction as possible. A minimal compaction effort is needed to keep the soil in contact with the mold walls and to prevent short-circuiting during the tests. The hand compacted soil specimens therefore have the least amount of compaction.

A series of controlled laboratory tests were conducted for comparison with the double-ring infiltration tests and to represent a wide range of soil conditions, as shown in Table 1. Six soil samples were tested, each at three different compaction levels described previously. Small depths of standing water on top of the soil test mixtures (4.3 inches, or 11.4 cm, maximum head) was also used. Most of these tests were completed within 3 hours, but some were continued for more than 150 hours. Only one to three observation intervals were used during these tests, so they did not have sufficient resolution or enough data points to attempt to fit to standard infiltration equations. However, these longer-term averaged values may be more suitable for infiltration rate predictions due to the high natural variability observed during the field tests. As shown, there was very little variation between the different time periods for these tests, compared to the differences between the compaction or texture groupings. The sandy soils can provide substantial infiltration capacities, even when compacted greatly, in contrast to the soils having clays that are very susceptible to compaction, resulting in near zero infiltration rates if compacted.

Table 1. Low-Head Laboratory Infiltration Tests for Various Soil Textures and Densities (densities and observed infiltration rates)

	Hand Compaction	**Standard Compaction**	**Modified Compaction**
Sand (100% sand)	Density: 1.36 g/cm^3 (ideal for roots) 0 to 0.48 hrs: 9.35 in/h 0.48 to 1.05 hrs: 7.87 in/h 1.05 to 1.58 hrs: 8.46 in/h	Density: 1.71 g/cm^3 (may affect roots) 0 to 1.33 hrs: 3.37 in/h 1.33 to 2.71 hrs: 3.26 in/h	Density: 1.70 g/cm^3 (may affect roots) 0 to 0.90 hrs: 4.98 in/h 0.90 to 1.83 hrs: 4.86 in/h 1.83 to 2.7 hrs: 5.16 in/h
Silt (100% silt)	Density: 1.36 g/cm^3 (close to ideal for roots) 0 to 8.33 hrs: 0.26 in/h 8.3 to 17.8 hrs: 0.24 in/h 17.8 to 35.1 hrs: 0.25 in/h	Density: 1.52 g/cm^3 (may affect roots) 0 to 24.2 hrs: 0.015 in/h 24.2 to 48.1: 0.015 in/h	Density: 1.75 g/cm^3 (will likely restrict roots) 0 to 24.2 hrs: 0.0098 in/h 24.2 to 48.1: 0.0099 in/h
Clay (100% clay)	Density: 1.45 g/cm^3 (may affect roots) 0 to 22.6 hrs: 0.019 in/h 22.6 to 47.5 hrs: 0.016 in/h	Density: 1.62 g/cm^3 (will likely restrict roots) 0 to 100 hrs: <2X10-3 in/h	Density: 1.88 g/cm^3 (will likely restrict roots) 0 to 100 hrs: <2X10-3 in/h
Sandy Loam (70% sand, 20% silt, 10% clay)	Density: 1.44 g/cm^3 (close to ideal for roots) 0 to 1.17 hrs: 1.08 in/h 1.17 to 4.37 hrs: 1.40 in/h 4.37 to 7.45 hrs: 1.45 in/h	Density: 1.88 g/cm^3 (will likely restrict roots) 0 to 3.82 hrs: 0.41 in/h 3.82 to 24.3 hrs: 0.22 in/h	Density: 2.04 g/cm^3 (will likely restrict roots) 0 to 23.5 hrs: 0.013 in/h 23.5 to 175 hrs: 0.011 in/h
Silty Loam (70% silt, 20% sand, 10% clay)	Density: 1.40 g/cm^3 (may affect roots) 0 to 7.22 hrs: 0.17 in/h 7.22 to 24.8 hrs: 0.12 in/h 24.8 to 47.1 hrs: 0.11 in/h	Density: 1.64 g/cm^3 (will likely restrict roots) 0 to 24.6 hrs: 0.014 in/h 24.6 to 144 hrs: 0.0046 in/h	Density: 1.98 g/cm^3 (will likely restrict roots) 0 to 24.6 hrs: 0.013 in/h 24.6 to 144 hrs: 0.0030 in/h
Clay Loam (40% silt, 30% sand, 30% clay)	Density: 1.48 g/cm^3 (may affect roots) 0 to 2.33 hrs: 0.61 in/h 2.33 to 6.13 hrs: 0.39 in/h	Density: 1.66 g/cm^3 (will likely restrict roots) 0 to 20.8 hrs: 0.016 in/h 20.8 to 92.8 hrs: 0.0066 in/h	Density: 1.95 g/cm^3 (will likely restrict roots) 0 to 20.8 hrs: <0.0095 in/h 20.8 to 92.8 hrs: 0.0038 in/h

Comparing Field and Laboratory Measurement Methods

A soil infiltration study was recently conducted by Redahegn Sileshi, a PhD student in the Department of Civil, Construction, and Environmental Engineering at the University of Alabama, in July 2011 at four test sites located in areas that were affected by the April 27, 2011 Tornado that devastated the city of Tuscaloosa, AL. Double-ring infiltration measurements (using three Turf-Tec infiltrometers at each location) were conducted to determine the infiltration characteristics of the soils in typical areas where reconstruction with stormwater infiltration controls is planned. The small field double-ring (4 inch, 10 cm, diameter) test results were compared to large (24 inch, 60 cm, diameter, 3 to 4 ft, 1 to 1.2 m, deep) pilot-scale borehole tests to identify if the small test methods can be accurately used for rapid field evaluations. The borehole tests required drilling a hole and placing a Sonotube cardboard concrete form into the hole to protect the sides of the hole. The borehole was 2 to 4 ft deep (depending on subsoil conditions). The bare soil at the bottom of the tube was roughened to break up any smeared soil and back-filled with a few inches of coarse gravel to prevent erosion during water filling. The tubes were filled with water from adjacent fire hydrants and the water elevation drop was monitored using a recording depth gage (a simple pressure transducer with a data logger).

In addition, controlled laboratory column tests were also conducted on surface and subsurface soil samples under the three different compaction conditions to see if depth of the test (and response to compaction) affected the infiltration results. The test sites were all located adjacent to fire hydrants (for water supply for the large borehole tests) and are located in the City's right-of way next to roads. Figure 3 shows some of the features of these tests.

Figure 3. Photographs showing borehole drilling, Sonotube infiltration tube installation, double-ring infiltration measurements, and laboratory column tests.

The soil densities of the surface soils averaged 1.7 g/cc (ranged from 1.6 to 1.9 g/cc). The median soil particle sizes averaged 0.4 mm (ranging from 0.3 to 0.7), and the soil had a clay content of about 20%. Figure 4 shows the saturated infiltration rates for the different locations and test methods.

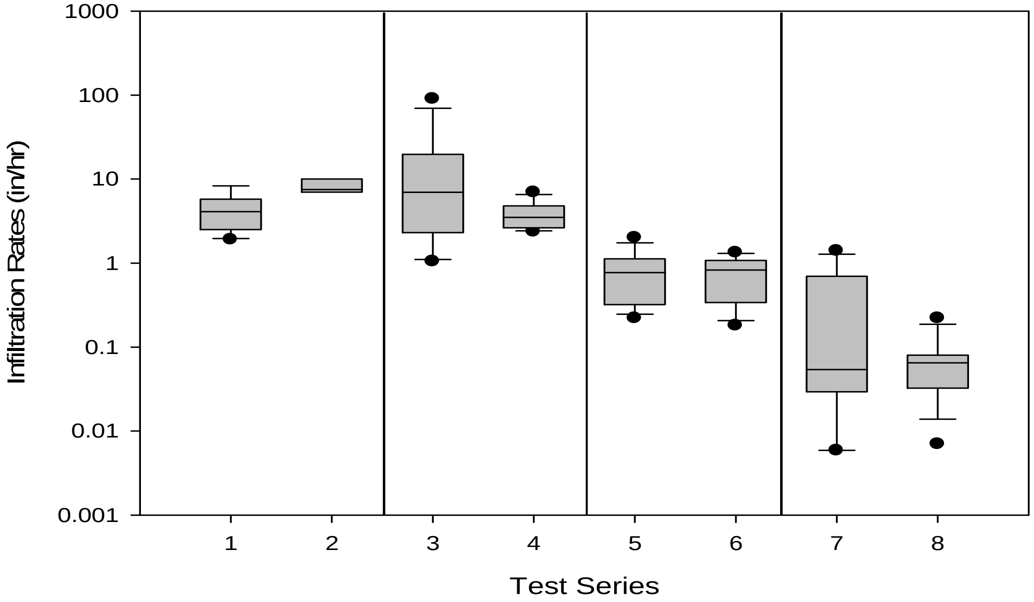


Figure 4. Box and whisker plots comparing saturated soil infiltration rates (in/hr). Test series descriptions (12 replicates in each test series except for the borehole tests which only included 3 observations):

1) Turf-Tec small double ring infiltrometer
2) Pilot-scale borehole infiltration tests
3) Surface soil composite sample with hand compaction (1.4 g/cc density)
4) Subsurface soil composite sample with hand compaction (1.4 g/cc density)
5) Surface soil composite sample with standard proctor compaction (1.6 g/cc density)
6) Subsurface soil composite sample with standard proctor compaction (1.6 g/cc density)
7) Surface soil composite sample with modified proctor compaction (1.7 g/cc density)
8) Subsurface soil composite sample with modified proctor compaction (1.7 g/cc density)

Using the double ring infiltrometers, the final saturated infiltration rates (of most significance when designing bioinfiltration stormwater controls) for all the test locations was found to average about 4.4 in/hr (11 cm/hr) for the 12 measurements and ranged from 1.9 to 8.3 in/hr (4.8 to 21 cm/hr). The borehole test results were about twice these values. The laboratory column tests indicated that surface and subsurface measurements were similar for all cases, but that compaction dramatically decreased the infiltration rates, as expected. The slightly (hand) compacted test results were similar to the Turf-Tec and the borehole test results, indicating that these sites, even in the road rights-of-ways, were minimally compacted. These areas were all originally developed more than 20 years ago and had standard turf grass covering. They were all isolated from surface disturbances, beyond standard landscaping maintenance. It is not likely that the tornado affected the soils. The soil profile (surface soils vs subsurface soils from about 4 ft, 1.2 m) did not affect the infiltration rates at these locations. Due to the relatively high clay content, the compaction tests indicated similarly severe losses in infiltration rates as found in prior studies, of one to two orders of magnitude reductions, from about 25, to 2, to 0.1 cm/hr, usually far more than the differences found between different soil textures.

Summary of Compaction Effects on Infiltration Tests

These recent tests indicated that the three soil infiltration test methods resulted in similar results, although the small –scale Turf-Tec infiltrometers indicated reduced rates compared to the borehole tests. Another study, summarized below, however indicated that the Turf-Tec infiltrometers resulted in substantially greater infiltration rates than observed in a failing bioinfiltration device, compared to actual infiltration rates during rain events. Therefore, if surface characteristics are of the greatest interest (such as infiltration through surface landscaped soils, as in turf areas, grass swales or in grass filters), the small-scale infiltrometers work well. These allow a cluster of measurements to be made in a small area to better indicate variability. Larger, conventional double-ring infiltrometers are not very practical in urban areas due to the excessive force needed to seat the units in most urban soils (usually requiring jacking from a heavy duty truck) and the length of time and large quantities of water needed for the tests. In addition, they also only measure surface soil conditions. More suitable large-scale (deep) infiltration tests would be appropriate when subsurface conditions are of importance (as in bioinfiltration systems and deep rain gardens). The borehole and Sonotube test used above is relatively easy and fast to conduct, if a large borehole drill rig is available along with large volumes of water (such as from a close-by fire hydrant). For infiltration facilities already in place, simple stage recording devices (small pressure transducers with data loggers) are very useful for monitoring during actual rain conditions.

In many cases, disturbed urban soils have dramatically reduced infiltration rates, usually associated with compaction of the surface soils. The saturated infiltration rates can be one to two orders of magnitude less than assumed, based on undisturbed/uncompacted conditions. Local measurements of the actual infiltration rates, as described above, can be a very useful tool in identifying problem areas and the need for more careful construction methods. Having accurate infiltration rates are also needed for proper design of stormwater bioinfiltration controls. In situations of adverse infiltration rates, several strategies can be used to improve the existing conditions, as noted below.

Summary of Compacted Soil Restoration Methods

Mechanical restoration of compacted clayey soils must be carefully done to prevent the development of a hardpan and further problems. Spading implements are the safest methods for large scale improvements. However, if large fractions of clay are present in the soil, the addition of sand and possibly also organic amendments may be needed. The use of periodic rain gardens in a large compacted area allows deeper soil profile remediation in a relatively small area and may be suitable to enhance drainage in problem locations.

To address water quality concerns and numeric effluent limits, water and soil chemistry information is needed in order to select the best amendments for a soil or biofilter media. As summarized by Clark and Pitt (Clark, S. and R. Pitt. “Filtered Metals Control in Stormwater using Engineered Media.” *ASCE/EWRI World Environment and Water Resources Congress*. Palm Springs, CA, May 22-26, 2011. Conference CD.), the removal of “dissolved” metals from stormwater by soils and amendments will need to be based on the ratio of valence states to determine the proportion of ion exchange resins versus organic-based media in the final media mixture. As more of the metal concentrations have either a 0 or +1 valence charge (as ions), or as more are associated with organic complexes, the smaller the fraction of an ion exchange resin, such as a zeolite, is needed. For metals such as thallium, where few inorganic and organic complexes are formed and where the predominant valence state is +2, increasing the amount of zeolite in the final media mixture is important for improving removal. Therefore, the final media mixture will be based on the pollutants of interest and their water chemistry. The capacity for pollutant removal by soils is directly related to OM and CEC content for many metals. Organic media provides a wide range of treatment sites besides increasing the CEC. Activating an organic media, such as granular activated carbon, will increase the number of surface active sites for treatment, but this media will not sustain plant growth by itself. As an example, copper removal capacity is related to soil carbon content, and CEC, plus, soil Mg content relates to the ability of the media to participate in ion exchange reactions.

Therefore, at least one component in an amendment media mixture should provide excellent ion exchange, such as would be found with a good zeolite. This media should be able to participate in reactions with the +2 metals and a portion of the +1 metals, although the +1 metals may not be as strongly bound and may be displaced if a more preferable exchangeable ion approaches the media's removal site. Soil OM, soil C, and soil N all relate to the organic matter content and indicate that these are sites that may participate in a variety of reactions and may be able to remove pollutants that do not carry a valence charge. Therefore, mixtures of amendments may be needed for effective removal of a range of pollutants: an organic component should be incorporated, along with a GAC. In most cases, sand may also be needed for structural support (to minimize compaction) and for controlling the flow rate to a level that allows for sufficient contact time.

Use of Compacted Soil Factors in WinSLAMM

WinSLAMM considers decreased infiltration rates associated with compaction when calculating runoff values for disturbed urban soils. For all pervious surfaces (landscaped areas, undeveloped areas, and for areas receiving flows from disconnected impervious area), the model user selects the level of compaction (normal, moderately, or severely compacted). The model uses the urban soil volumetric runoff ratio (from the calibrated *.rsv file) for normal soils. However, the example factors shown in Table 2 (suggested values based on the field and laboratory research) are used to modify these values for compacted soil conditions.

Table 2. Example Infiltration Rate Factors Associated with Various Levels of Soil Compaction

	sandy	silty	clayey
Normal urban soils (a slight amount of compaction expected due to urbanization, especially with well-established and healthy vegetation)	1.00	1.00	1.00
Moderately compacted (near buildings or other structures associated with construction, or compacted with use)	0.50	0.20	0.10
Severely compacted (the highest level of compaction possible associated with extreme use)	0.20	0.10	0.00

The factors shown in Table 2 are user accessible as part of the tools/program options/default model options and are saved in the *.ini file. As an example, if the normal Rv (the ratio of runoff volume to rainfall volume) for a silty soil was 0.35 for a specific rain condition, the modified value associated with moderately compacted conditions increases due to the compacted conditions, using the following relationships:

Normal amount of infiltration (plus evapotranspiration) with Rv of 0.35: 1 - 0.35 = 0.65

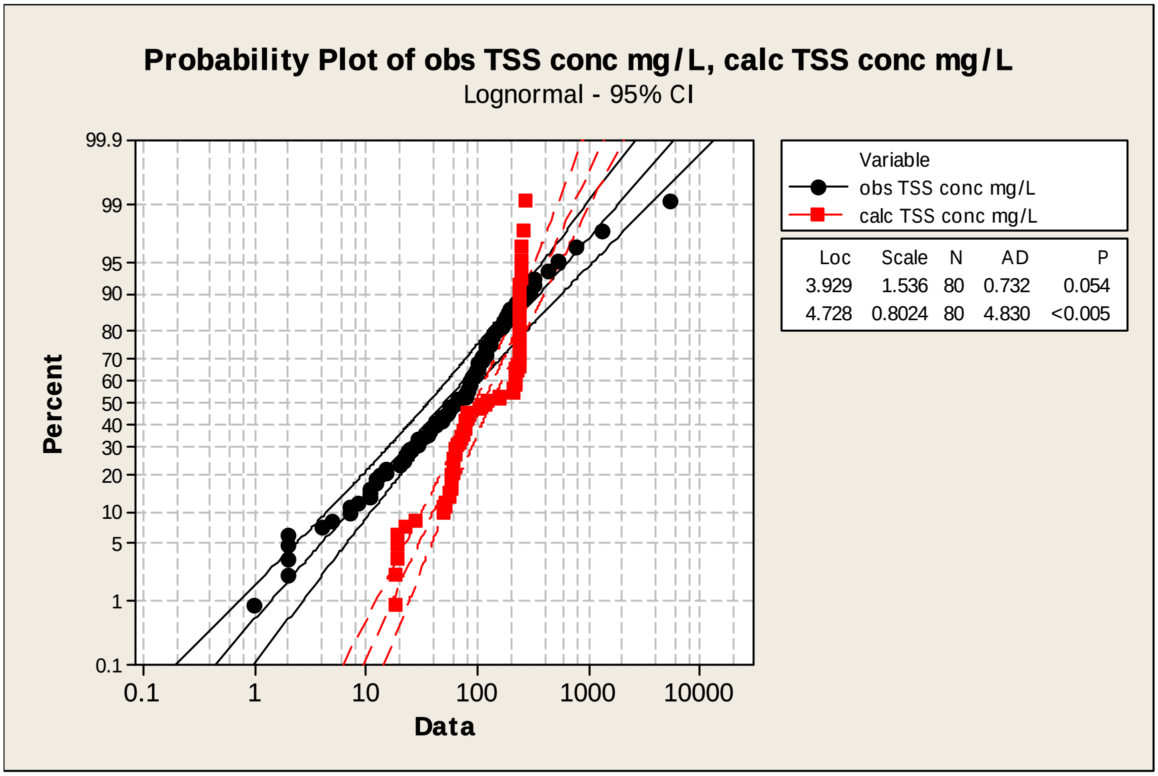
With a compaction factor of 0.20, only 1/5 of the normal amount of infiltration would actually infiltrate: 0.2*0.65 = 0.13

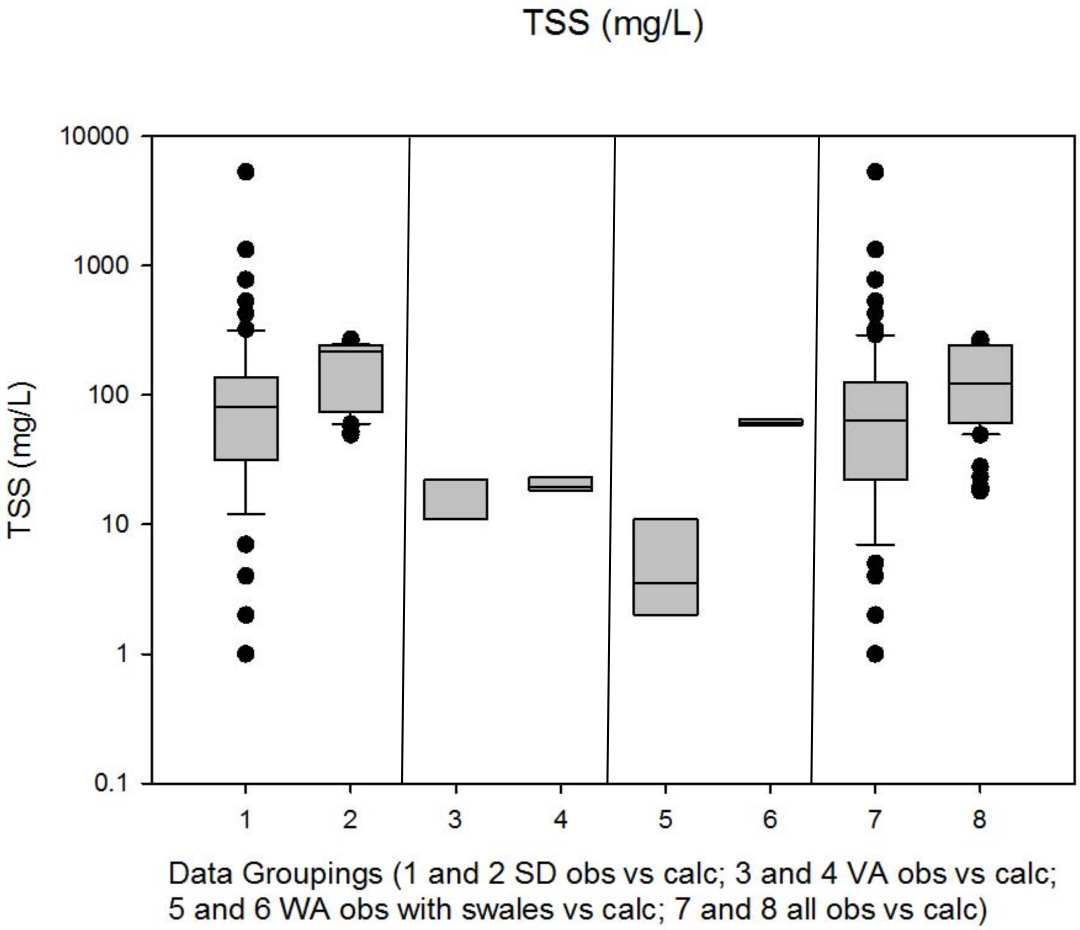
And the new adjusted Rv associated with moderately compacted silty soils for that rain would therefore be: 1-0.13 = 0.87

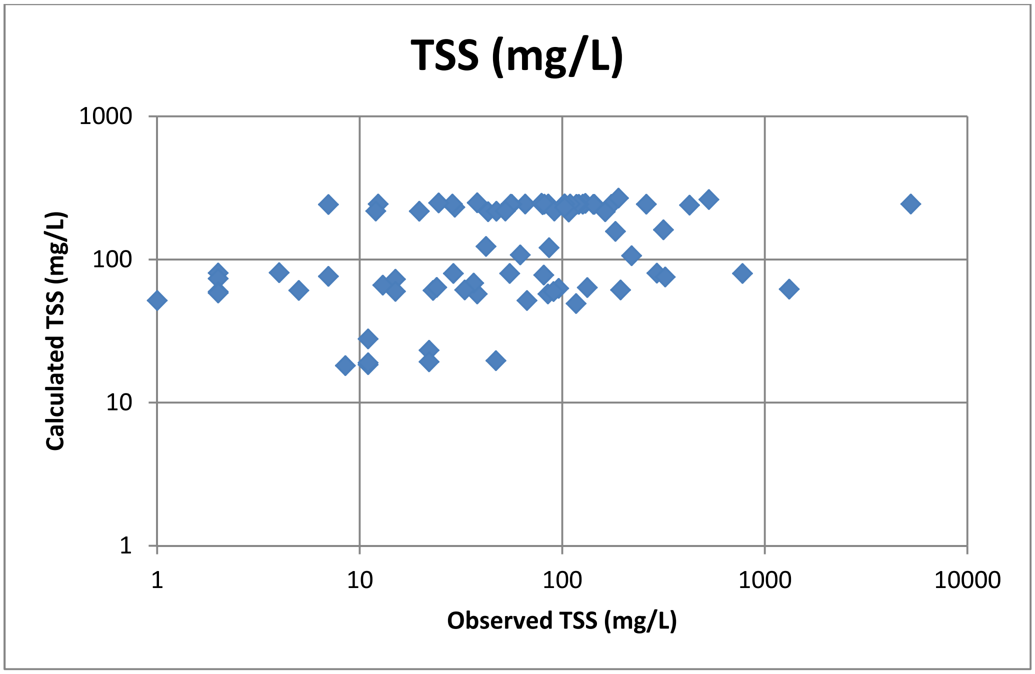
Therefore: adjusted Rv = 1-((1- normal Rv)*factor), or: 1-((1-0.35)*0.2) = 0.87

Appendix C: Calibration Analyses

TSS Concentration Calibrations




TSS (mg/L)
TSS (mg/L)
10000
1000
100
10
1
0.1
1
2
3
4
5
6
7
8
Data Groupings (1 and 2 SD obs vs calc; 3 and 4 VA obs vs calc;
5 and 6 WA obs with swales vs calc; 7 and 8 all obs vs calc)


TSS (mg/L)
Calculated TSS (mg/L)
1000
100
10
1
1
10
100
1000
10000
Observed TSS (mg/L)

Mann-Whitney Rank Sum Test Results for TSS Concentrations for San Diego Sites

Group	N	Missing	Median	25%	75%
SD obs TSS mg/L	69	0	81.667	31.25	137.667
SD calc TSS mg/L	69	0	215.7	74.43	243.15
Mann-Whitney U Statistic= 1489.000					
T = 3904.000 n(small)= 69 n(big)= 69 (P = <0.001)					

The difference in the median values between the two groups is greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

Mann-Whitney Rank Sum Test Results for TSS Concentrations for Virginia Sites

Group	N	Missing	Median	25%	75%
VA obs TSS mg/L	7	0	11	11	22
VA calc TSS mg/L	7	0	19.27	18.4	23.17
Mann-Whitney U Statistic= 17.000					
T = 45.000 n(small)= 7 n(big)= 7 P(est.)= 0.368 P(exact)= 0.383					

The difference in the median values between the two groups is not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.383)

Mann-Whitney Rank Sum Test Results for TSS Concentrations for Washington Sites

Group	N	Missing	Median	25%	75%
WA obs TSSmg/L	4	0	3.5	2	11
WA calc TSS mg/L	4	0	60.11	58.57	64.785
Mann-Whitney U Statistic= 0.000					
T = 10.000 n(small)= 4 n(big)= 4 P(est.)= 0.029 P(exact)= 0.029					

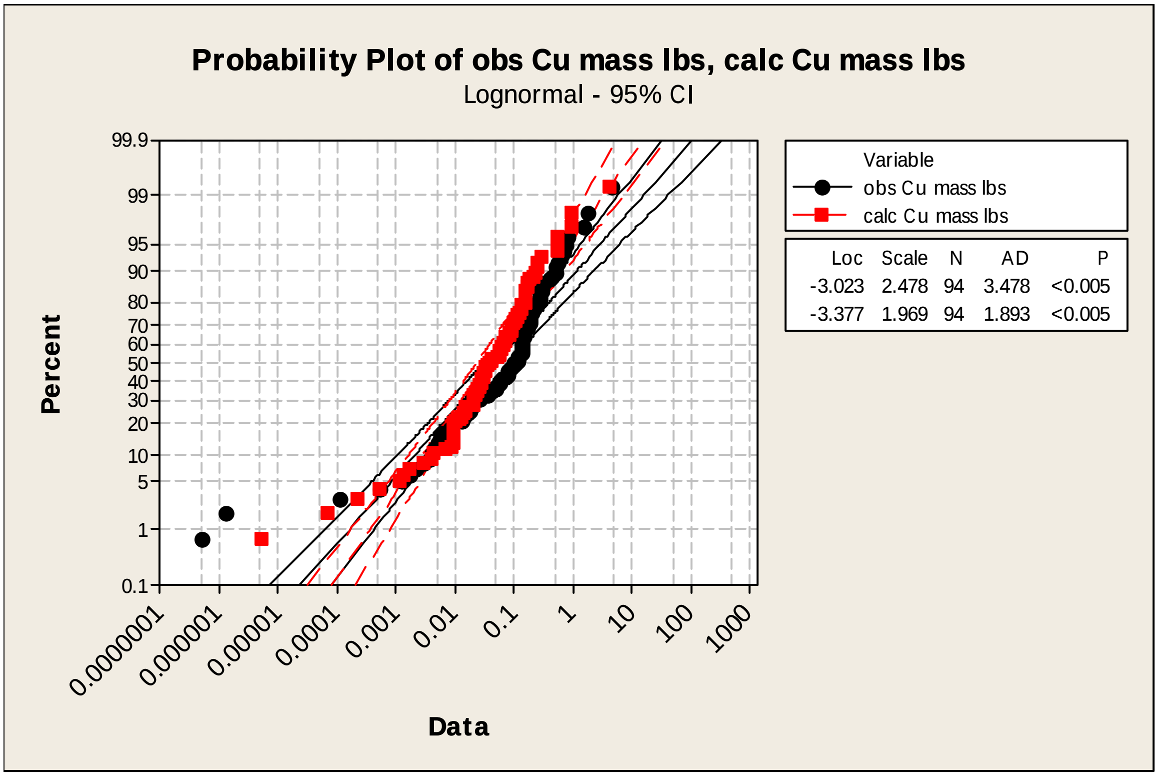
The difference in the median values between the two groups is greater than would be expected by chance; there is a statistically significant difference (P = 0.029)

Mann-Whitney Rank Sum Test Results for TSS Concentrations for All Sites Combined

Group	N	Missing	Median	25%	75%
all obs TSS mg/L	80	0	63.833	22	124.917
all calc TSS mg/L	80	0	122.05	61.42	242.875
Mann-Whitney U Statistic= 2075.000					
T = 5315.000 n(small)= 80 n(big)= 80 (P = <0.001)					

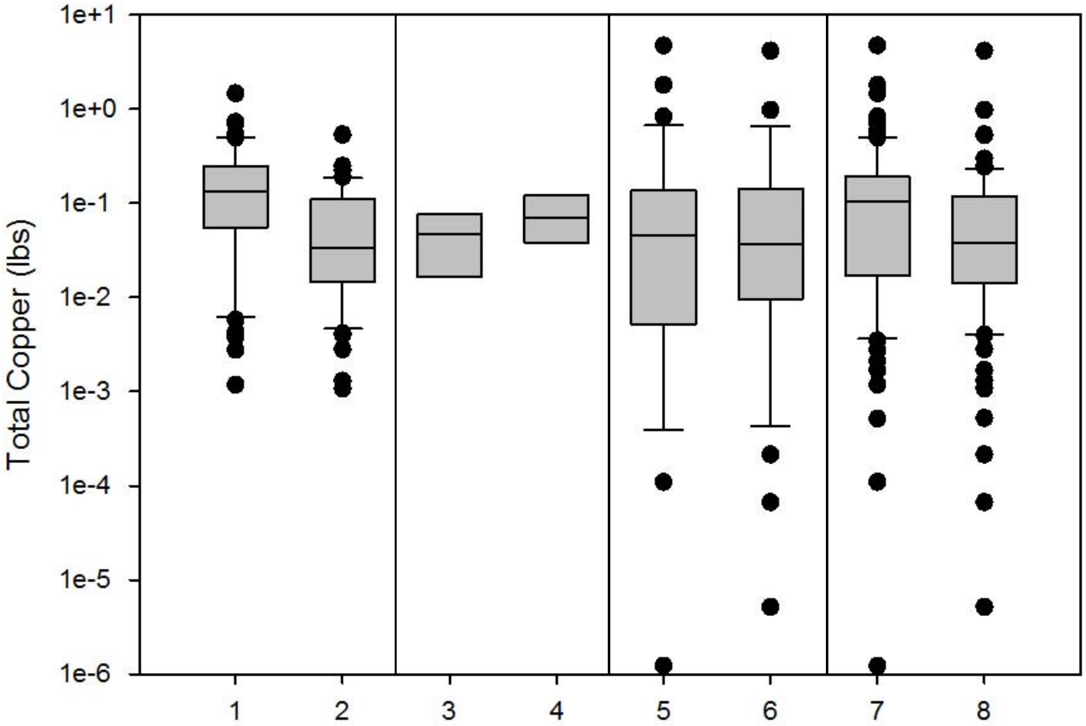
The difference in the median values between the two groups is greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

Copper Mass Calibrations

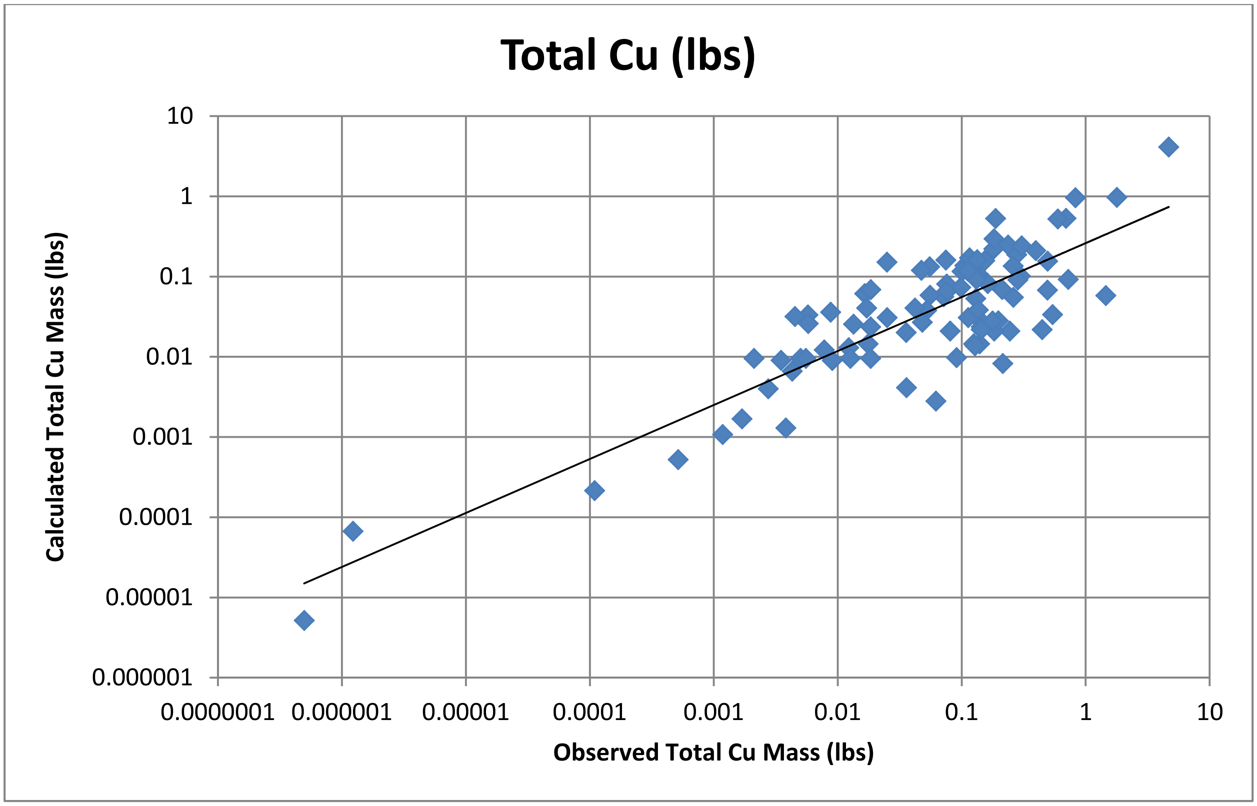


Loc	Scale	N	AD	P
-3.023	2.478	94	3.478	<0.005
-3.377	1.969	94	1.893	<0.005

Total Copper (lbs)



Data Groupings (1 and 2 SD obs vs calc; 3 and 4 VA obs vs calc; 5 and 6 WA obs vs calc; 7 and 8 all combined obs vs calc)



Mann-Whitney Rank Sum Test Results for Total Copper Mass Loadings for San Diego Sites

Group	N	Missing	Median	25%	75%
SD obs Cu lbs	51	0	0.135	0.0551	0.245
SD calc Cu lbs	51	0	0.0333	0.0145	0.109
Mann-Whitney U Statistic= 775.000					
T = 3152.000 n(small)= 51 n(big)= 51 (P = <0.001)					

The difference in the median values between the two groups is greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

Mann-Whitney Rank Sum Test Results for Total Copper Mass Loadings for Virginia Sites

Group	N	Missing	Median	25%	75%
VA obs Cu lbs	7	0	0.0473	0.0165	0.0756
VA calc Cu lbs	7	0	0.0686	0.0379	0.12
Mann-Whitney U Statistic= 15.000					
T = 43.000 n(small)= 7 n(big)= 7 P(est.)= 0.250 P(exact)= 0.259					

The difference in the median values between the two groups is not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.259)

Mann-Whitney Rank Sum Test Results for Total Copper Mass Loadings for Washington Sites

Group	N	Missing	Median	25%	75%
WA obs Cu lbs	36	0	0.045	0.00514	0.135
WA calc Cu lbs	36	0	0.0371	0.00956	0.143
Mann-Whitney U Statistic= 625.000					
T = 1291.000 n(small)= 36 n(big)= 36 (P = 0.800)					

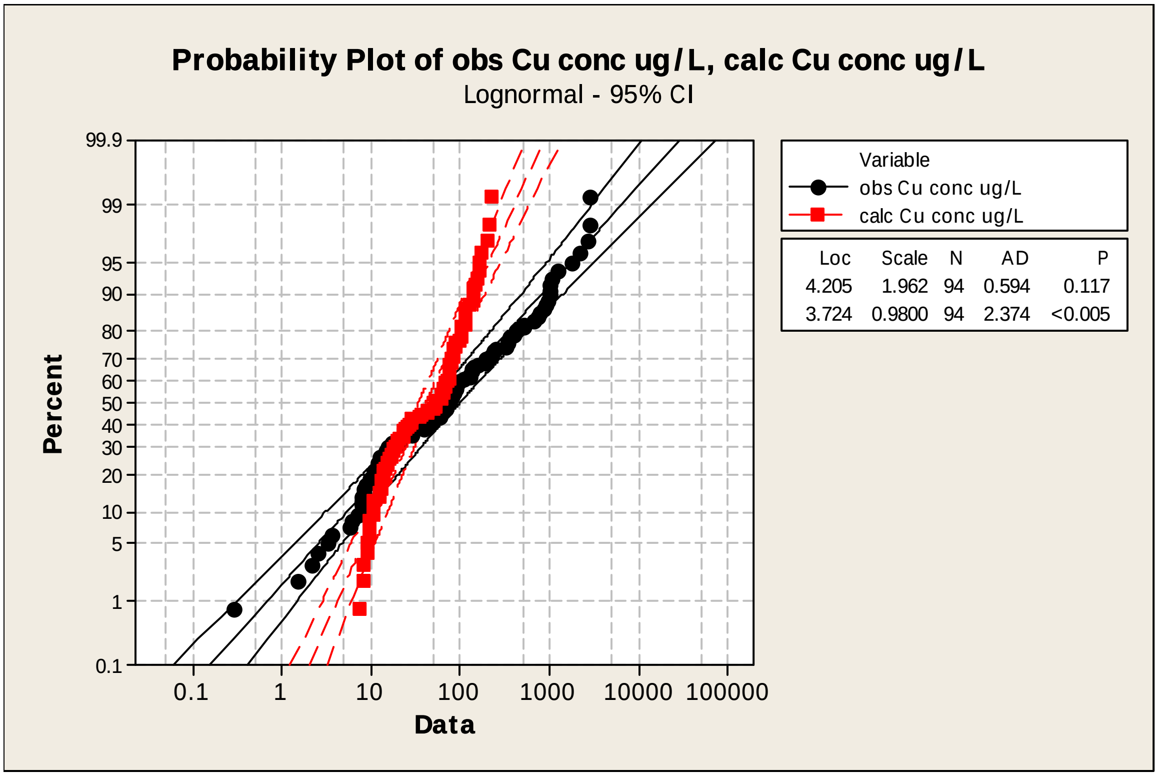
The difference in the median values between the two groups is not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.800)

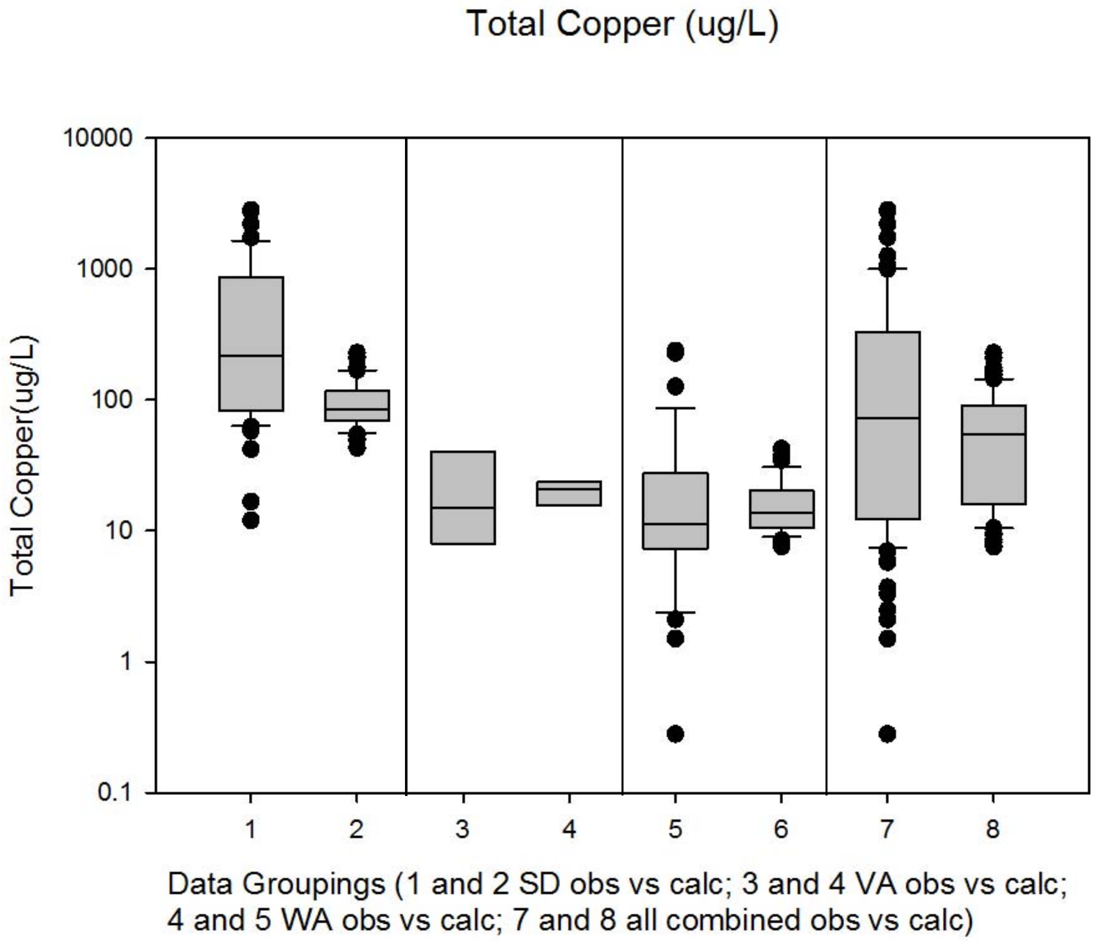
Mann-Whitney Rank Sum Test Results for Total Copper Mass Loadings for All Sites Combined

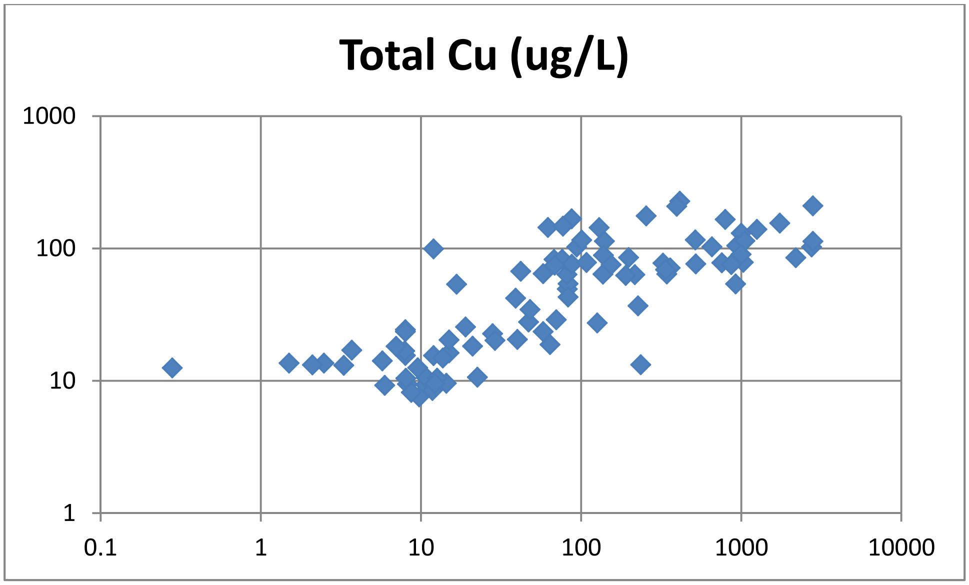
Group	N	Missing	Median	25%	75%
all obs Cu lbs	94	0	0.103	0.017	0.19
all calc Cu lbs	94	0	0.0381	0.0143	0.118
Mann-Whitney U Statistic= 3625.000					
T = 9676.000 n(small)= 94 n(big)= 94 (P = 0.034)					

The difference in the median values between the two groups is greater than would be expected by chance; there is a statistically significant difference (P = 0.034)

Copper Concentration Calibrations




Total Copper (ug/L)
Total Copper(ug/L)
10000
1000
100
10
1
0.1
1
2
3
4
5
6
7
8
Data Groupings (1 and 2 SD obs vs calc; 3 and 4 VA obs vs calc;
4 and 5 WA obs vs calc; 7 and 8 all combined obs vs calc)



Mann-Whitney Rank Sum Test Results for Total Copper Concentrations for San Diego Sites

Group	N	Missing	Median	25%	75%
SD obs Cu ug/L	51	0	216.667	83	866.667
SD calc Cu ug/L	51	0	85.34	69.3	116.1
Mann-Whitney U Statistic= 664.000					
T = 3263.000 n(small)= 51 n(big)= 51 (P = <0.001)					

The difference in the median values between the two groups is greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

Mann-Whitney Rank Sum Test Results for Total Copper Concentrations for Virginia Sites

Group	N	Missing	Median	25%	75%
VA obs Cu ug/L	7	0	15	8	40
Va calc Cu ug/L	7	0	20.56	15.55	23.57
Mann-Whitney U Statistic= 21.000					
T = 49.000 n(small)= 7 n(big)= 7 P(est.)= 0.701 P(exact)= 0.710					

The difference in the median values between the two groups is not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.710)

Mann-Whitney Rank Sum Test Results for Total Copper Concentrations for Washington Sites

Group	N	Missing	Median	25%	75%
WA obs Cu ug/L	36	0	11.3	7.225	27.375
WA calc Cu ug/L	36	0	13.625	10.45	20.348
Mann-Whitney U Statistic= 547.000					
T = 1213.000 n(small)= 36 n(big)= 36 (P = 0.258)					

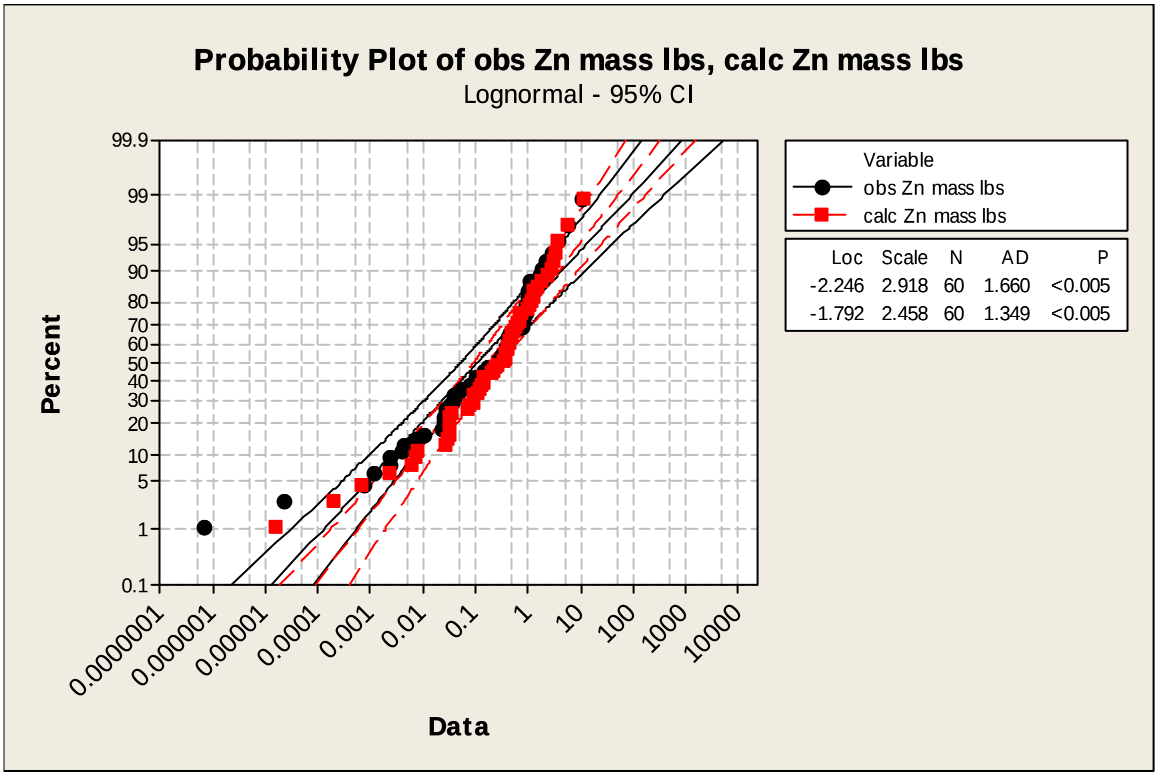
The difference in the median values between the two groups is not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.258)

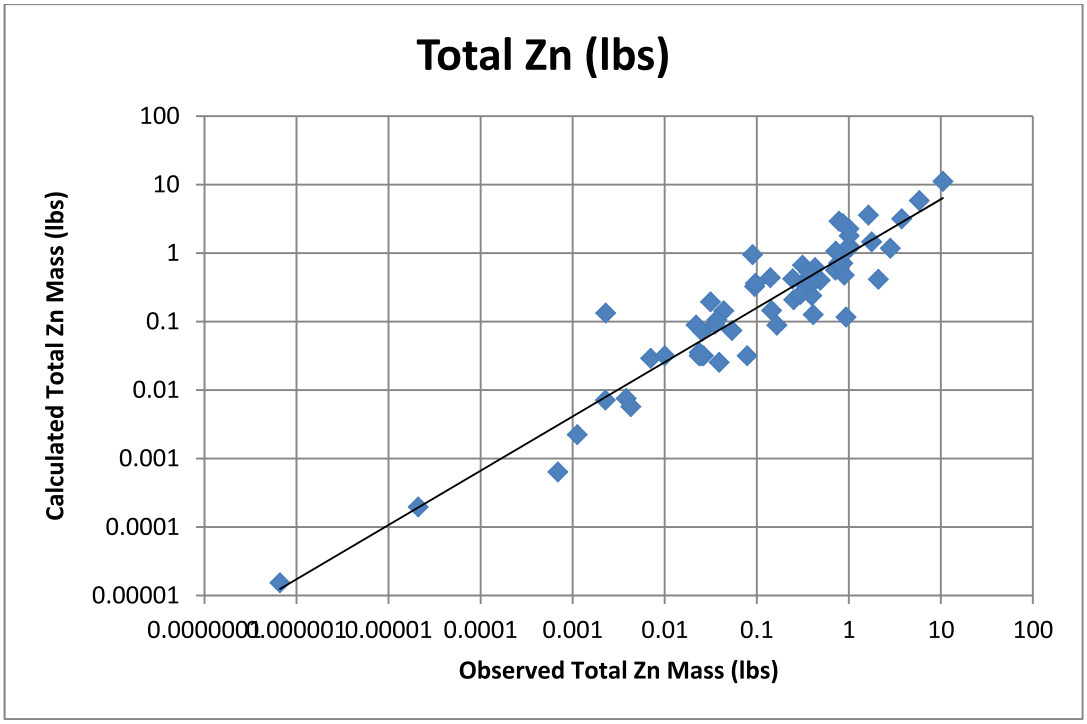
Mann-Whitney Rank Sum Test Results for Total Copper Concentrations for All Sites Combined

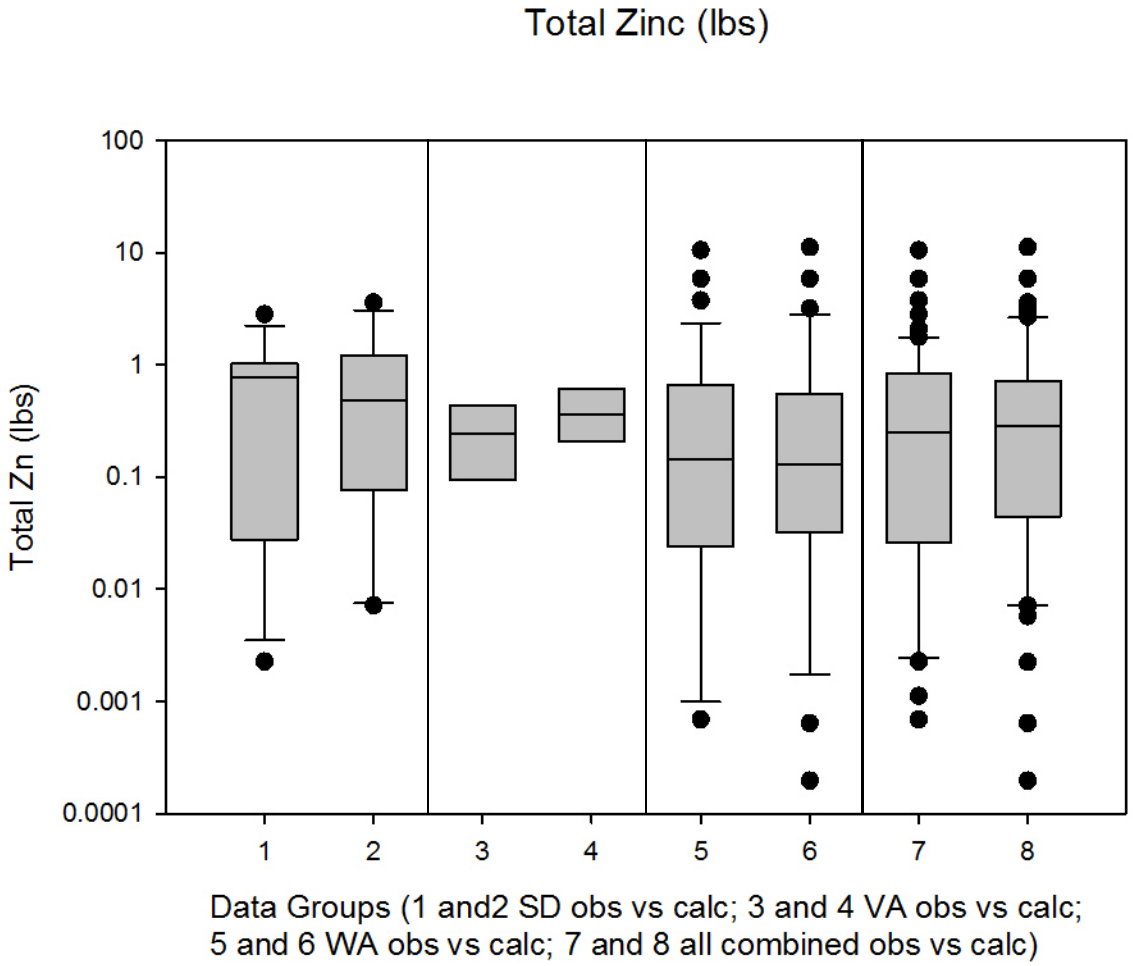
Group	N	Missing	Median	25%	75%
all obs Cu ug/L	94	0	73.1	12.15	327.917
all calc Cu ug/L	94	0	54.115	16.105	89.368
Mann-Whitney U Statistic= 3809.000					
T = 9492.000 n(small)= 94 n(big)= 94 (P = 0.103)					

The difference in the median values between the two groups is not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.103)

Zinc Mass Calibrations




Total Zn (lbs)
Calculated Total Zn Mass (lbs)
100
10
1
0.1
0.01
0.001
0.0001
0.00001
0.0000001
0.000001
0.00001
0.0001
0.001
0.01
0.1
1
10
100
Observed Total Zn Mass (lbs)



Mann-Whitney Rank Sum Test Results for Total Zinc Mass Loadings for San Diego Sites

Group	N	Missing	Median	25%	75%
SD obs Zn lbs	17	0	0.781	0.0276	1.02
SD calc Zn lbs	17	0	0.477	0.0763	1.222
Mann-Whitney U Statistic= 127.000					
T = 280.000 n(small)= 17 n(big)= 17 (P = 0.558)					

The difference in the median values between the two groups is not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.558)

Mann-Whitney Rank Sum Test Results for Total Zinc Mass Loadings for Virginia Sites

Mann-Whitney Rank Sum Test	Saturday, November 16, 2013, 10:38:17 PM				
Group	N	Missing	Median	25%	75%
VA obs Zn lbs	7	0	0.246	0.095	0.43
VA calc Zn lbs	7	0	0.363	0.208	0.617
Mann-Whitney U Statistic= 15.000					
T = 43.000 n(small)= 7 n(big)= 7 P(est.)= 0.250 P(exact)= 0.259					

The difference in the median values between the two groups is not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.259)

Mann-Whitney Rank Sum Test Results for Total Zinc Mass Loadings for Washington Sites

Group	N	Missing	Median	25%	75%
WA obs Zn lbs	36	0	0.143	0.024	0.659
WA calc Zn lbs	36	0	0.13	0.0317	0.556
Mann-Whitney U Statistic= 609.000					
T = 1275.000 n(small)= 36 n(big)= 36 (P = 0.665)					

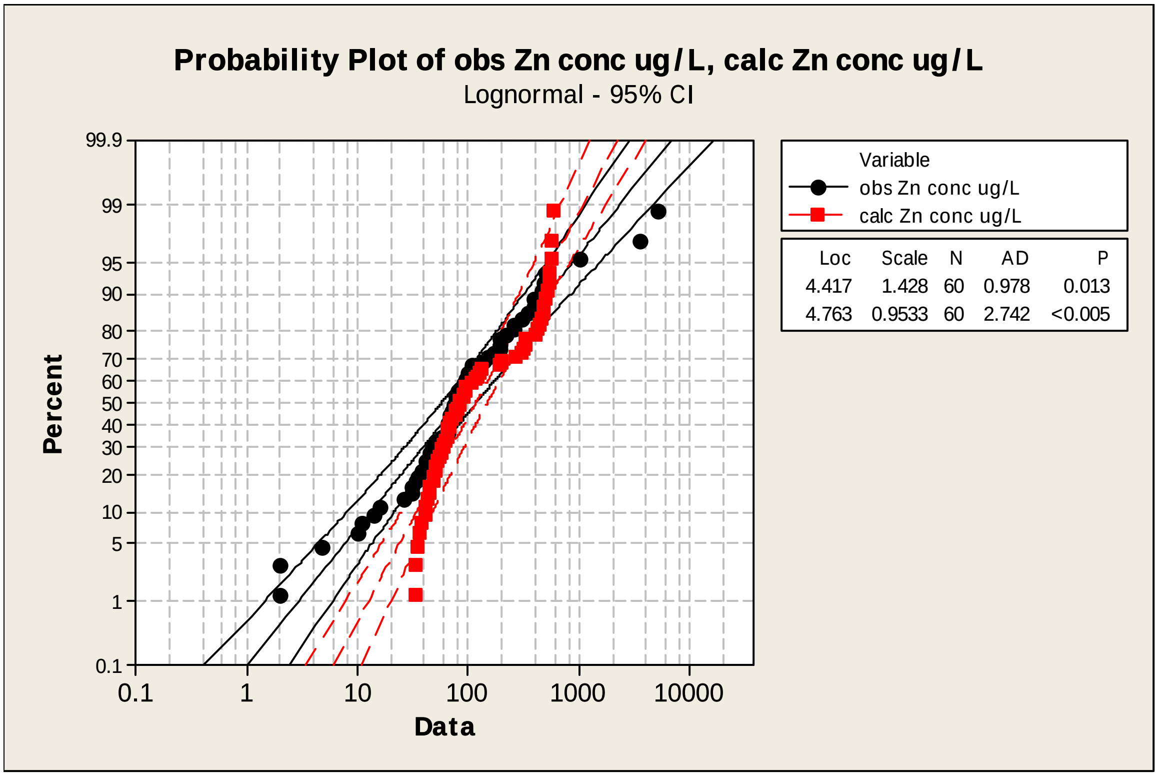
The difference in the median values between the two groups is not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.665)

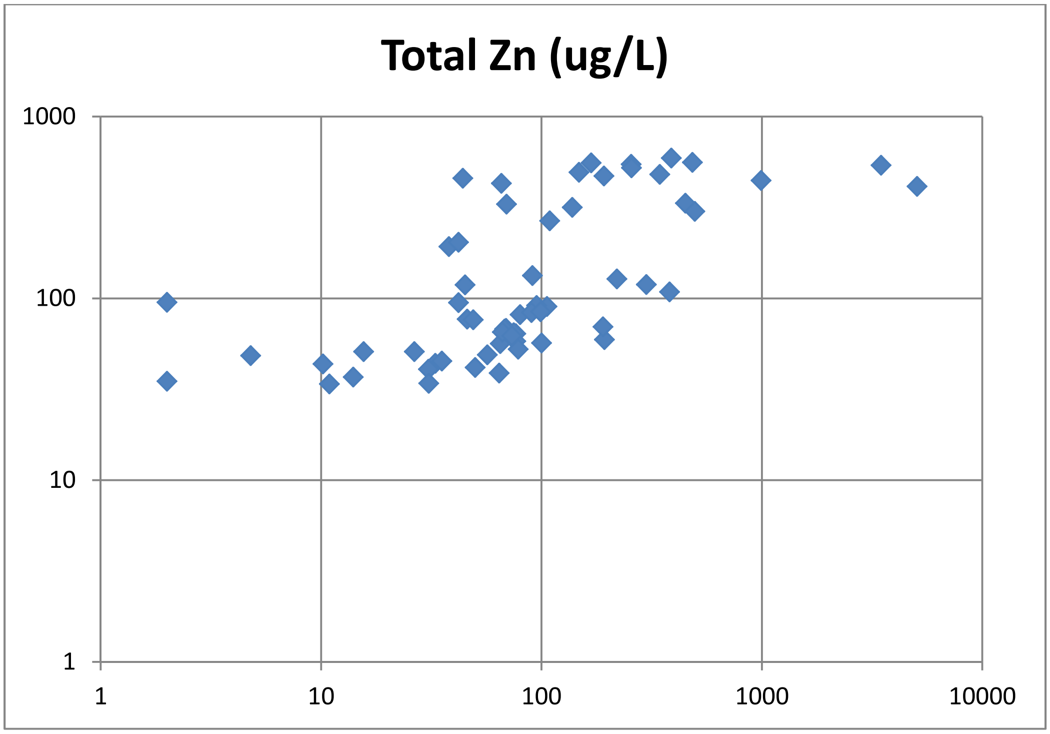
Mann-Whitney Rank Sum Test Results for Total Zinc Mass Loadings for All Sites Combined

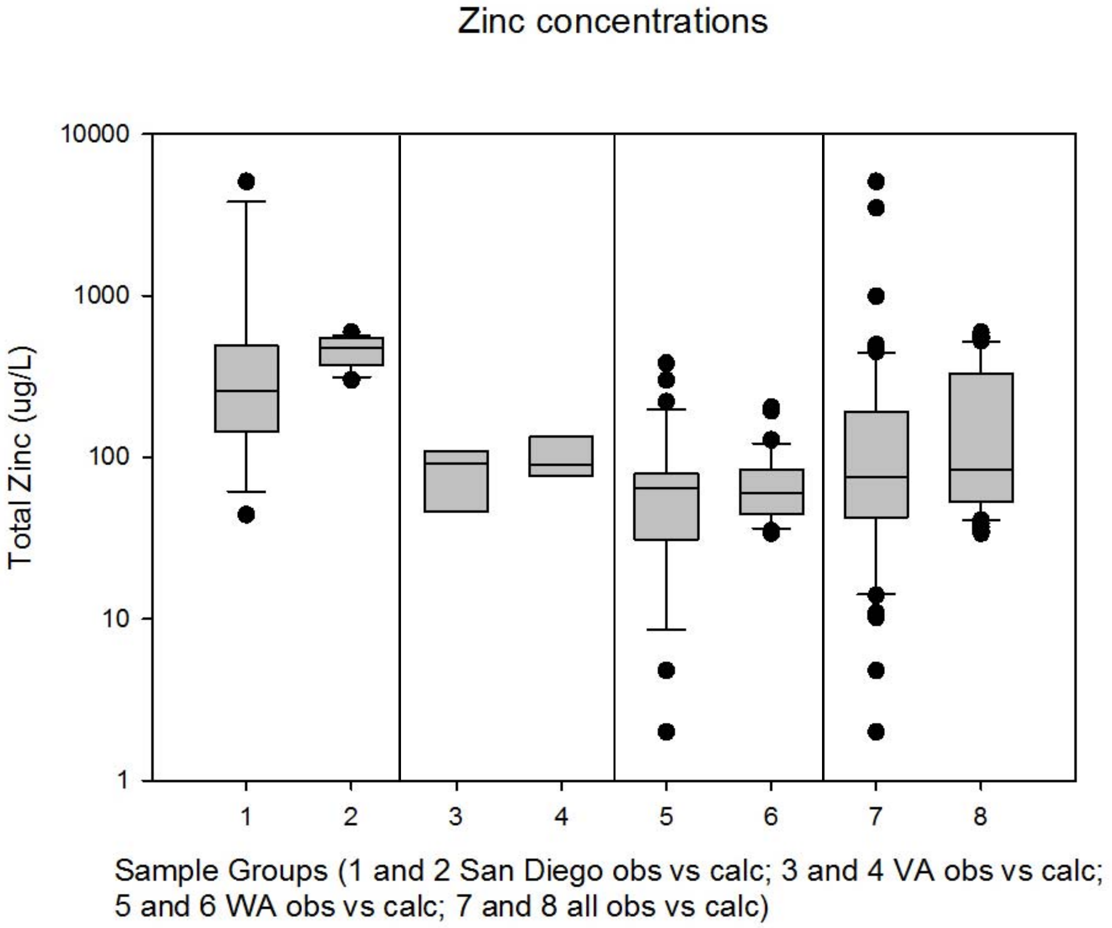
Group	N	Missing	Median	25%	75%
all obs Zn lbs	60	0	0.249	0.0257	0.842
all calc obs Zn lbs	60	0	0.288	0.0446	0.717
Mann-Whitney U Statistic= 1652.000					
T = 3482.000 n(small)= 60 n(big)= 60 (P = 0.439)					

The difference in the median values between the two groups is not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.439)

Zinc Concentration Calibrations







Mann-Whitney Rank Sum Test Results for Total Zinc Concentrations for San Diego Sites

Group	N	Missing	Median	25%	75%
SD obs Zn ug/L	17	0	256	143	490
SD calc Zn ug/L	17	0	471	373.4	542.6
Mann-Whitney U Statistic= 87.000					
T = 240.000 n(small)= 17 n(big)= 17 (P = 0.050)					

The difference in the median values between the two groups is greater than would be expected by chance; there is a statistically significant difference (P = 0.050)

Mann-Whitney Rank Sum Test Results for Total Zinc Concentrations for Virginia Sites

Group	N	Missing	Median	25%	75%
VA obs Zn ug/L	7	0	91	46	109
VA calc Zn ug/L	7	0	90.14	76.19	133.3
Mann-Whitney U Statistic= 20.000					
T = 48.000 n(small)= 7 n(big)= 7 P(est.)= 0.609 P(exact)= 0.620					

The difference in the median values between the two groups is not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.620)

Mann-Whitney Rank Sum Test Results for Total Zinc Concentrations for Washington Sites

Group	N	Missing	Median	25%	75%
WA obs Zn ug/L	36	0	64.65	30.725	79.6
WA calc Zn ug/L	36	0	60.14	44.247	84.16
Mann-Whitney U Statistic= 571.000					
T = 1237.000 n(small)= 36 n(big)= 36 (P = 0.389)					

The difference in the median values between the two groups is not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.389)

Mann-Whitney Rank Sum Test Results for Total Zinc Concentrations for All Sites Combined

Group	N	Missing	Median	25%	75%
all obs Zn ug/L	61	1	75.6	42.5	191.5
all calc Zn ug/L	61	1	83.96	53.435	326.45
Mann-Whitney U Statistic= 1541.000					
T = 3371.000 n(small)= 60 n(big)= 60 (P = 0.175)					

The difference in the median values between the two groups is not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.175)